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THE ROYAL AERONAUTICAL SOCIETY

NOVEMBER 1961

CONTENTS

NOTICES

EDWARD RAYMOND SHARP—AN APPRECIATION — E. S. MOULT

THE AGENA SATELLITE AND THE DISCOVERER PROGRAMME — R. SMELT

THE GENERATION OF SOUND BY AERODYNAMIC MEANS — N. CURLE

A METHOD OF ESTIMATING THE PERMISSIBLE FATIGUE LIFE OF THE WING STRUCTURE OF A TRANSPORT AIRCRAFT — K. D. RAITHBY

A REVIEW OF CURRENT DEVELOPMENTS IN AGRICULTURAL AVIATION — W. E. RIPPER

LIQUID ATOMISATION — R. P. FRASER

THE FARMER'S VIEWPOINT ON AERIAL APPLICATION OF FERTILISERS AND SPRAYS — J. B. FARRANT

FUTURE DEVELOPMENTS IN AGRICULTURAL AVIATION — A. H. WHEELER

THE ROYAL AERONAUTICAL SOCIETY: THE FIRST FIFTY YEARS—1876-1877 — J. LAURENCE PRITCHARD

TECHNICAL NOTES

A Note on the Choice of Co-ordinate Functions for the Rayleigh-Ritz Method—J. SINGER. The Pressure Registered by a Very Small Static Hole—J. D. JACKSON. The Production of Peak Velocity Profiles. P. G. MORGAN and A. SAUNDERS (August Journal)—Correction by D. C. ROBERTS.

THE BRANCHES

GRADUATES' AND STUDENTS' SECTION

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THE ROYAL AERONAUTICAL SOCIETY

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CONTENTS

		PAGE
Notices Agricultural Aviation Group Symposium—Rotorcraft Section Symposium—H B. Irving Award—Honours Awarded to Members—Membership Subscriptions—Associate Fellowship Examination—Conference Photographs—Symposium on Cleaning and Materials Processing—A.S.T.M. Change of Name—Christmas Holiday—Journal Binding Prices—Diary—Society of Weight Engineers National Conference—Elections—Associate Fellowship Examination Results—School of Welding Technology—Analogue Computing—News of Members—A Letter from Mrs. Florence M. Taylor, of Australia—Lecture Summaries.		XLV
Edward Raymond Sharp—An Appreciation	E. S. MOULT	711
The Agena Satellite and the Discoverer Programme	R. SMELT	713
The Generation of Sound by Aerodynamic Means	N. CURLE	724
A Method of Estimating the Permissible Fatigue Life of the Wing Structure of a Transport Aircraft	K. D. RAITHBY	729
A Review of Current Developments in Agricultural Aviation	W. E. RIPPER	739
Liquid Atomisation	R. P. FRASER	749
The Farmer's Viewpoint on Aerial Application of Fertilisers and Sprays	J. B. FARRANT	756
Future Developments in Agricultural Aviation	A. H. WHEELER	759
The Royal Aeronautical Society: The First Fifty Years—1876-1877	J. LAURENCE PRITCHARD	762
Technical Notes A Note on the Choice of Co-ordinate Functions for the Rayleigh-Ritz Method—J. SINGER. The Pressure Registered by a Very Small Static Hole—J. D. JACKSON. The Production of Peak Velocity Profiles. P. G. MORGAN and A. SAUNDERS (August Journal)—Correction by D. C. ROBERTS.		765
The Branches		768
Graduates' and Students' Section		769
The Library REVIEWS: Always Another Dawn—Aerofoil Sections—Flight Briefing for Pilots—Angewandte Stromungslehre—Stress Concentration Around Holes—Missile Configuration Design—Gas Sampling and Chemical Analysis in Combustion Processes—Applied Thermodynamics. ADDITIONS TO THE LIBRARY. REPORTS.		770

All communications for publication in the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., F.R.Ae.S., Hon.F.C.A.I., F.I.A.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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(Founded 1866)

Patron: Her Majesty The Queen

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Note: Under the revised By-Laws, allowed on 11th January 1960, the President of each Division and the Chairman of each Section of the Society is a Member of Council by reason of his office.

NOTICES

H. B. Irving Award

The H. B. Irving Award has been founded by Mrs. Norah S. Irving in memory of her husband Mr. H. B. Irving (*Fellow*), Chairman of the first Man Powered Aircraft Group Committee of the Society, who died in January 1961 as a result of a motor accident.

The following are the terms of the Award:—

1. The Award to be known as the H. B. Irving Award.
2. The Award to be made, at the discretion of the Council, for the best paper published in one of the Society's publications on the subject of Man Powered Flight.
3. The Award to be made for five years only, 1962-1966 inclusive.
4. The Award to take the form of a cheque for 25 guineas. The winner also to receive an engraved "H. B. Irving Memorial Medal."

Note: The best paper published in 1960 or 1961 will be eligible for the first Award.

Honours Awarded to Members

The Daniel Guggenheim Medal

Mr. Jerome Lederer, Director of the Flight Safety Foundation, *Fellow* of the Society, has been awarded the Daniel Guggenheim Medal for 1961, "for lifelong dedication to the cause of flight safety and his constant and untiring efforts to reduce the hazards of aviation."

The Institute of Navigation

The Bronze Medal of the Institute of Navigation has been awarded to Mr. E. S. Calvert (*Fellow*) the originator of the Calvert strip lighting system, for his paper "Manoeuvre to Ensure the Avoidance of Collision" which was published in Volume 13 of the *Institute of Navigation Journal*.

Associate Fellowship Examination—December 1961

The next Associate Fellowship Examination will be held on Tuesday, Wednesday, Thursday and Friday, the 12th, 13th, 14th and 15th December. All candidates will be sent a detailed timetable.

Symposium on Cleaning and Materials Processing for Electronics and Space Apparatus

A Symposium on Cleaning and Materials Processing for Electronics and Space Apparatus will be held during the Fourth Pacific Area National Meeting of the American Society for Testing and Materials at the Statler-Hilton Hotel, Los Angeles, California, from 30th September to 5th October 1962. All individuals interested in presenting a paper are asked to submit the title and a 200-word abstract to Dr. D. E. Koontz, Bell Telephone Laboratories, Inc., Murray Hill, N.J., *not later than* 1st *January* 1962.

The Symposium will deal extensively with materials and processing problems common to electronic devices and device fabrication and the chemistry and physics of their operation, as well as similar problems encountered in production in space apparatus. These subjects fall into four broad categories: (*i*) Examination of device materials, (*ii*) Treatment and examination of specific components, (*iii*) Processing facilities, such as chemical agents, processing liquids and ambients, including dust and lint control, (*iv*) Device experience with ultra-clean conditions.

ASTM Change of Name

The name of the American Society for Testing Materials has been officially changed to the American Society for Testing *AND* Materials. The abbreviation ASTM will be retained.

Christmas Holiday

The Offices and Library of the Society will be closed from Friday afternoon, 22nd December, until 9 a.m. on Wednesday 27th December.

Rotorcraft Section—All-Day Symposium, 1st December 1961

An all-day symposium will be held by the Rotorcraft Section on 1st December 1961 in the Lecture Theatre, 4 Hamilton Place, London, W.1, beginning at 9.30 a.m.

There will be four lectures as follows, each of which will be followed by a discussion:

(*i*) Lessons Gained on Helicopter Air Traffic Control from FAA Activities—Richard A. Fitzek.
(*ii*) Operations of Chicago Helicopter Airways —A. Angstadt.
(*iii*) The Westland 192 Helicopter—A. McClements.
(*iv*) The Sikorsky Crane Helicopter—Philip L. Michel.

Admission will be by ticket only. Tickets may be obtained from The Secretary, Royal Aeronautical Society, 4 Hamilton Place, London, W.1.

Agricultural Aviation Group

An All-Day Meeting on The Uses of the Aeroplane in Agriculture will be held in the Lecture Theatre, 4 Hamilton Place, London, W.1, on Wednesday, 13th December 1961, from 10.0 a.m. until 5.30 p.m.

There will be four lectures as follows:

"The Operator's Year," by Wg. Cdr. P. R. Hatfield of Airspray (Colchester) Ltd.

"The Aerial Spraying of Forest Areas," by Dr. Myles Crooke of the Department of Forestry, University of Aberdeen.

"Chemical Cultivation and Re-seeding from the Air," by Professor J. W. Calder of Twyford Seeds Limited and H. M. Lawson, Advisory Agronomist to Dow Agrochemicals Ltd.

"Agricultural Aircraft for the Future"—Three short talks on fixed wing, helicopter and gyrocopter aspects.

The lectures will each be followed by a discussion, and a General Discussion will close the proceedings. Further details and programmes may be obtained from the Secretary of the Agricultural Aviation Group. Visitors are welcome.

Membership Subscriptions 1962

For the convenience of members it has been decided to issue reminders to those resident in the United Kingdom approximately one month before the 1962 subscriptions become due on 1st January next. This new form has been designed to incorporate the various notes previously published in the Journal, but overseas members will continue to receive their individual reminders in the previous manner.

Conference Photographs

The photographs taken during the 8th Anglo-American Conference of delegates and their wives will be on show in the Hall at 4 Hamilton Place for the next few months. Copies of any of the photographs may be ordered at 1s. 6d. each.

Journal Binding

Because of increased costs of materials and labour during the past two years, the charge for permanent binding of Journals has, unfortunately, had to be increased. The new charges are:—

1960 Volume (including packing and postage *in the United Kingdom*) ... ... £1 7s. 6d.
Previous Volumes (including packing and postage *in the United Kingdom*) ... ... £1 10s. 0d.

Journals, with a note of the name and address of the sender, should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Society.

Members are asked to be certain that the address to which they want their Journals sent is the same on their letters to The Lewes Press and to the Society.

DIARY

Note: A Lecture Card giving the complete programme for the 1961-62 Session was enclosed with the October JOURNAL.

MAIN SOCIETY

All lectures in London will be held in the Lecture Theatre, 4 Hamilton Place, unless otherwise stated.

16th November
SEVENTEENTH BRITISH COMMONWEALTH LECTURE—The Progress of European Air Transport 1946-61 with particular reference to B.E.A. Lord Douglas of Kirtleside. 6 p.m.

21st November
Military Ground Effect Vehicles. W. H. Coulthard. 6 p.m.

23rd November
Flight Characteristics of the B-58 Mach 2 Bomber. B. A. Erickson. 6 p.m.

13th December
MAIN LECTURE AT THE MANCHESTER BRANCH—Airlines Approach to Aircraft Selection. Monsieur R. Nivet. Reynolds Hall, College of Technology, Manchester. 7 p.m.

4th January
YOUNG PEOPLE'S LECTURE—Airliners of the Future. Godfrey H. Lee, Handley Page Ltd. 3 p.m.

ASTRONAUTICS AND GUIDED FLIGHT SECTION

14th November
A Comparison of the Control Problems of Missiles and Manned Aircraft. K. W. Smith. 6 p.m.

12th December
Military Design Requirements of Guided Missiles. Brigadier E. W. Denison. 6 p.m.

GRADUATES' AND STUDENTS' SECTION

22nd November
Army Aviation. Colonel C. D. S. Kennedy. 7 p.m.

24th November
Winter Dance. 8 p.m.-11.45 p.m. Double tickets 15s.

6th December
Watch for Posters.

ROTORCRAFT SECTION

1st December
All-Day Symposium. 9.30 a.m. *See* special notice.

AGRICULTURAL AVIATION GROUP

13th December
All-Day Symposium—*See* special notice.

HISTORICAL GROUP

27th November
The Society's Library and Aeronautical History. F. H. Smith. 6 p.m.

MAN POWERED AIRCRAFT GROUP

17th November
Aerodynamics of Man Powered Aircraft. T. R. F. Nonweiler. 6 p.m.

15th December
Problems of a Man Powered Rotorcraft. R. A. Graves. 6 p.m.

BRANCHES

14th November
Glasgow—All-Day Symposium. Airframe Production. J. Woods. Engine Production. F. T. Salt. Scottish Aviation Ltd., Prestwick Airport. 10.30 a.m.

16th November
Birmingham and Wolverhampton—Blind Landing Developments. W. J. Charnley, Birmingham.
Cheltenham—Corrosion. G. Richards. St. Mary's College, The Park. 7.30 p.m.

17th November
Luton—Annual Dinner. Leicester Arms Hotel, Luton.

21st November
Boscombe Down—Branch Dinner.

22nd November
Reading and District—Branch Lectures or Film Show. Western Manufacturing (Reading) Ltd. 6.15 p.m.
Southampton—NINTH MITCHELL MEMORIAL LECTURE. The Strength of England. Dr. Barnes N. Wallis. University Engineering Lecture Theatre. 8 p.m.
Glasgow—Development of the Conway By-Pass Engine. L. G. Dawson. Rolls-Royce Ltd., East Kilbride. 7.15 p.m.

27th November
Henlow—Presidential Address. The Development of Aircraft for the R.A.F. D. E. Morris. Assembly Hall, R.A.F. Technical College, Henlow. 7.45 p.m.

29th November
Weybridge—The R. K. Pierson Memorial Lecture. Sir Geoffrey Tuttle, K.B.E. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd., Weybridge. 5.45 p.m.

1st December
Reading and District—Annual Dinner-Dance. The "White Hart" Hotel, Sonning.

4th December
Derby—Annual General Meeting. Design and Development of the Rolls-Royce Conway. L. G. Dawson. Rolls-Royce Welfare Hall, Nightingale Road. 6.15 p.m.

5th December
Bristol—Aircraft Flight Safety and Missile Reliability. Air Vice Marshal H. B. Wrigley. Conference Room, Filton House, Bristol Aircraft Ltd., Filton. 6 p.m.

6th December
Brough—Vertical Take-Off by Jet Lift. D. Keith-Lucas. 7.30 p.m.
London Airport—Aviation Fuels. W. S. Little. Lecture Hall, Faireys, Hayes. 6.15 p.m.

11th December
Boscombe Down—Members Meeting (Junior Members lecture competition). 5.30 p.m.
Henlow—Rebuilding and Flying Historic Aircraft. Air Cdre. A. H. Wheeler. Assembly Hall, R.A.F. Technical College, Henlow. 7.45 p.m.

12th December
Luton—707 Operation. Capt. H. L. Fry. The Napier Senior Staff Canteen, Luton Airport. 6 p.m.

13th December
Christchurch—Film Show: Antarctic Crossing. Sir Vivian Fuchs. King's Arms Hotel. 7.30 p.m.
Luton—Schools Lecture: How an Aircraft is Built. F. W. Buglass. Luton Technical School. 2.30 p.m.
Reading and District—Making Aircraft Films. G. M. Shipway. Western Manufacturing (Reading) Ltd. 6.15 p.m.
Southampton—Pioneering Aeronautical Development in Brazil. K. L. C. Legg. Engineering Lecture Theatre, University of Southampton. 8 p.m.

14th December
Cheltenham—New Developments in Aircraft Propulsion. Dr. S. G. Hooker. St. Mary's College, The Park. 7.30 p.m.
Coventry—Junior lectures and films. The Herbert Art Gallery, Coventry. 7.30 p.m.
Glasgow—Graduates' and Students' Section: Historic Aircraft. D. Carrick. Scottish Aviation, Prestwick. 7.30 p.m.

15th December
Weybridge—Annual Dance.

19th December
Glasgow—The Place of Wind Tunnel Research in the Development of a New Aeroplane. K. B. J. G. Asbeck Brusse. Glasgow University, W.2. 7.15 p.m.

S.A.W.E. NATIONAL CONFERENCE—14TH-17TH MAY 1962

The 21st National Conference of the Society of Aeronautical Weight Engineers will be held at the Benjamin Franklin Hotel in Seattle, Washington from 14th-17th May 1962. Technical papers will be presented on weight engineering problems related to aircraft, missiles, and space vehicles and their components and equipment. In addition, technical papers dealing with the weight and balance aspects of land and marine vehicles are requested. Panel discussions of current problems are scheduled for the Military Sessions. Parallel Airline Sessions will be held dealing with operational weight engineering problems. An Electronic Component and System Session is also planned.

All companies, airlines, manufacturers and agencies associated with the weight and balance aspects of air, space, land or sea vehicles and their components are invited to present papers at this conference.

An abstract (approximately 100 words) summarising the materials as well as sketches or any other data which will enable the programme committee to select papers of greatest interest and usefulness, must be submitted to one or other of the following people *by 15th January* 1962. Three hundred copies of papers accepted will be required.

General Weight Topics and Aircraft (including Land and Marine) to A. S. Hutchinson, Chairman, SAWE General Sessions, 335 Evers Street, Bridgeport, Conn.

Space and Missile Topics to O. A. Kelley, Jr., President, SAWE, 24 Turning Mill Road, Lexington 73, Mass.

Airline Topics to A. F. Devenish, Chairman, SAWE Airline Sessions, Trans-Canada Airlines, International Aviation Building, Montreal, Canada.

Electronic Component and System Topics to Ed Langleben, Chairman, SAWE Electronic Component and System Session, 7015 Plymouth, University City, Missouri.

Elections

The following is a list of elections and transfers of membership of the Society:

Associate Fellows

John Edward Alasia (*from Graduate*)
Benjamin Jesse Folliard
Harvey S. Greenfield
John Desmond Gurney (*from Graduate*)
Dennis Hughes (*from Associate*)
West Gordon Jones
Edward Geoffrey Lewis (*ex-Graduate*)
John Edward Medgett
Charles Marshall Mould
Claude Alan Patching
Sunder Lal Relan (*from Graduate*)
Nilkanth Janardan Shendge (*from Graduate*)
Colin Sydney Sinnott
Eugene Stolarik
Kenneth Robert Stevenson

Associates

Kirill Andrew Bolonkin (*from Student*)
Frank William Burton
Robert Frederick Gager
Patrick Joseph McKenzie
Jozef Wojciech Peckowski
Roy Bernard Selwyn
Ronald Wilks (*from Student*)

Graduates

Pritam Lal Bajaj (*from Student*)
Terence Edward Base (*from Student*)
John Francis Branton
Charles Bryant (*from Student*)
Michael George Coggins
John Philip Davie
Annesley De Soyza
Michael John Dodd
Bryan Robert Clifford Dowling
Edward Christopher Graham
Atiqul Hasan
Pedro John Meinrath
Noel Edwin Trigg
David Kingsley Wigley

Students

Michael Edwards
Geoffrey James Ives
Graham Jenkins
Norman Alexander Mitchell
Thomas Arwel Roberts
Kenneth Alan Stevens
Terence Lee Woodcock

Companions

Nadine Demulder
Laurence Sinclair
Ronald Frederick Willmott

Associate Fellowship Examination

The following candidates were successful in the Associate Fellowship Examination held in June 1961.

Part I—United Kingdom Candidates

R. D. Brown, Aerodynamics, Strength of Aircraft Materials and Theory of Structures.

I. R. Christie-Miller, Aerodynamics, Strength of Aircraft Materials and Theory of Structures. P. Coulson, Aerodynamics, Strength of Aircraft Materials and Theory of Structures.

M. E. Elmuthanna, Mechanics, Strength of Aircraft Materials and Theory of Structures, Thermodynamics.

M. C. S. Harris, Strength of Aircraft Materials and Theory of Structures. A. J. F. Hunt, Strength of Aircraft Materials and Theory of Structures.

K. G. Lilley, Aerodynamics, Strength of Aircraft Materials and Theory of Structures.

K. R. L. Read, Aerodynamics, Strength of Aircraft Materials and Theory of Structures. J. D. Rostron, Strength of Aircraft Materials and Theory of Structures.

J. Swaine, Aerodynamics, Strength of Aircraft Materials and Theory of Structures.

M. Tin Tun, Theory of Machines.

Part II—United Kingdom Candidates

M. N. Baker, Aerodynamics A, Aerodynamics B, Theory of Structures A, Theory of Structures B.

R. A. Cardozo, Thermodynamics and Theory of Machines. D. C. D. Coope, Theory of Structures A, Theory of Structures B, Theory of Structures C.

G. Dickinson, Theory of Structures A, Theory of Structures B, Theory of Structures C, Thermodynamics and Theory of Machines.

B. C. Foote, Theory of Structures A, Theory of Structures B, Aircraft Design and Development A.

W. G. Gillies, Theory of Structures B, Theory of Structures C.

J. Harrall, Air Transport, Meteorology, Operational Air Transport. G. S. Hewson, Theory of Structures A, Theory of Structures B.

J. Kime, Meteorology, Operational Air Transport.

G. H. Loadsman, Theory of Structures A, Theory of Structures B, Theory of Structures C.

R. V. Myers, Aircraft Design and Development A.

R. K. Satjadibrata, Theory of Structures A, Theory of Structures B. D. J. Shingier, Theory of Structures A, Theory of Structures B, Thermodynamics and Theory of Machines. P. L. Snowden, Theory of Structures A, Theory of Structures B.

G. A. Watson, Theory of Structures A, Theory of Structures B, Aircraft Design and Development B, Thermodynamics and Theory of Machines.

P. J. Yorke, Theory of Structures A, Theory of Structures B, Economics and Management.

Part I—Candidates from Abroad

D. S. Badwal, Delhi. Pure Mathematics, Mechanics, Physics, Thermodynamics.

R. Chander, Delhi. Aerodynamics, Thermodynamics. S. P. Chaudhary, Lucknow. Theory of Machines.

D. Lal, Lucknow. Pure Mathematics, Mechanics, Physics, Thermodynamics (Distinction), Theory of Machines.

K. P. Ramaswamy, Bombay. Strength of Aircraft Materials and Theory of Structures.

F. J. Sterk, Delft. Mechanics, Physics, Aerodynamics, Strength of Aircraft Materials and Theory of Structures. T. R. V. Subbu, Bangalore. Mechanics, Aerodynamics, Strength of Aircraft Materials and Theory of Structures.

Part II—Candidates from Abroad

V. P. Arora, Bangalore. Theory of Structures A, Theory of Structures B.

B. B. Julka, Kanpur. Thermodynamics and Theory of Machines, General Design, Piston and Turbine Engines, Piston and Turbine Engines.

M. Madhavan, Madras. Theory of Structures C. J. McFarlane, Germany. Theory of Structures A, Theory of Structures B.

M. P. Sethi, Delhi. Thermodynamics and Theory of Machines, General Design, Piston and Turbine Engines, Piston and Turbine Engines

School of Welding Technology

The School of Welding Technology is organising the second of the Advanced Courses for Welding Engineers in November. One of the objects of the advanced courses is to give British welding engineers the opportunity of learning first hand of developments in foreign countries and to provide an opportunity of discussing problems of mutual interest with leading experts from abroad. This year, five leading foreign authorities are visiting the School, as follows:—M. H. P. Granjon, Ing.ESSA, Les. S. —Engineer and Director of Studies at the Ecole Superieure de Soudure Autogene, Institut de Soudure, Paris. Dr. H. Krautkramer, Dr.rer.nat.—Gesellschaft fur Electrophysik, Cologne. Professor N. N. Rykalin, Dr.Tech.Sci.—U.S.S.R. Academy of Sciences, Moscow. Professor W. Soete, Ir. —Director, Laboratorium voor Weerstand Van Materialen, University of Ghent, Belgium. Dr. R. Sohngen, Ing. —Farbenfabriken Bayer A.G. Leverkusen, W. Germany.

Analogue Computing

A series of eleven weekly lectures on Analogue Computing has been started by the Bristol College of Science and Technology for engineers and mathematicians

on Wednesdays from 7-9 p.m. The fee for the course is £2 2s. 0d. or 10s. 6d. for a single lecture. Details may be obtained from K. Humphreys, Organiser of Short Courses, Bristol College of Science and Technology.

News of Members

R. J. Atkinson (*Fellow*) formerly Head of the Fatigue Division of the Structures Department of the Royal Aircraft Establishment, has been appointed Head of the Structures Department.

E. G. Barber (*Associate Fellow*) formerly Education Officer, Vickers-Armstrongs (Aircraft), has been appointed Group Education Officer, British Aircraft Corporation Ltd.

Captain E. C. Beard (*Fellow*) having retired from the Royal Navy, has joined the de Havilland Engine Company Ltd., Stag Lane.

Viscount Caldecott (*Associate Fellow*), Deputy Managing Director and Chief Executive (Guided Weapons), British Aircraft Corporation, and Managing Director English Electric Aviation Ltd., has been appointed to the Board of Napier Aero Engines Ltd.

K. S. R. Child (*Associate Fellow*) formerly Project Engineer at Raytheon, Massachusetts, is now Senior Engineer, Weapons Systems Division, The Martin Company, Baltimore.

C. H. Cooke (*Graduate*) formerly Senior Stressman i/c Birmingham Office, Sir W. G. Armstrong Whitworth Aircraft Ltd., is now Design Engineer at Rolls-Royce Ltd., Crewe.

D. H. Coxhead (*Associate*) formerly with British United Airways (Engineering Division), has been appointed Technical Secretary, The British Air Line Pilots Association.

G. A. Cropper (*Associate Fellow*) formerly an Aerodynamicist at de Havilland Aircraft of Canada Ltd., has been appointed Surveyor to the Air Registration Board, Chancery Lane, London.

M. C. Curties (*Associate Fellow*) formerly Senior Development Engineer (Instruments) with British European Airways, is now Senior Project Engineer (V.T.C.L. Systems) in the Aircraft Equipment Department, Ferranti Ltd., at Bracknell.

P. J. Daglish (*Associate Fellow*) formerly Commercial Director, D. Napier & Son Ltd., has been appointed Managing Director, D. Napier & Son Ltd.

Lt. Gen. Sir John Evetts (*Companion*) has retired and relinquished his directorship of Dowty Fuel Systems Ltd. He will devote his time and energy, on a voluntary basis, to furthering the aims of The Three Counties Industrial Education Association of which he is President and Chairman of Council.

J. R. Ewans (*Fellow*) formerly Director and Chief Engineer, A. V. Roe (Aircraft), has been appointed Technical Sales Manager (Military Aircraft) British Aircraft Corporation.

V. J. Glanville (*Associate*) formerly a Squadron Engineer Officer at R.A.F. Tengan, Singapore, has retired from the R.A.F. and is with the A.I.S. at No. 23 M.U., R.A.F. Aldergrove, N. Ireland.

A. H. C. Greenwood (*Associate Fellow*) formerly Director (Sales and Service) Vickers-Armstrongs Ltd., has been appointed Manager, Aircraft Sales and Service, British Aircraft Corporation.

J. E. Gwilliam (*Associate*) formerly Lecturer Bristol Siddeley Engines Ltd., is now Senior Electrical Instructor, Caltex Pacific Oil Company, Singapore.

N. M. F. Heaton (*Graduate*) formerly Scientist with Vickers Research Ltd., Sunninghill, Berkshire, is now Control Systems Engineer in the Atomic Energy Department of Babcock & Wilcox Ltd.

N. Herbert (*Associate Fellow*) formerly at the College of Technology, Chesterfield, has been appointed Head of the Department of Engineering Trades at the David College, Glasgow.

J. A. Jacobs (*Associate Fellow*) has been awarded the D.Sc. Degree by the University of London for his contributions to geophysics. He is a Professor of Geophysics at the University of British Columbia, Vancouver, Canada and has just been appointed Director of the newly-formed Institute of Earth Sciences on that Campus.

B. W. James (*Associate*) formerly Chief Project Engineer with de Havilland Aircraft Company Ltd., is now Production Engineer with Hunting Aircraft Ltd., Luton.

D. J. Lambert (*Associate Fellow*) formerly Assistant General Manager (Development), Vickers-Armstrongs (Aircraft) Ltd., has been appointed Technical Sales Manager (Civil Aircraft) British Aircraft Corporation.

A. A. Lombard (*Fellow*), Director of Engineering, Aero Engine Division, Rolls-Royce Ltd., has been appointed a Director of Napier Aero Engines Ltd.

Flt. Lt. H. J. Mould (*Associate Fellow*) formerly with R.A.F. Transport Command, has joined No. 5 Advanced Guided Weapons Course at R.A.F. Technical College, Henlow.

J. D. Pearson (*Fellow*), Managing Director, Aero Engine Division, and Deputy Chairman, Rolls-Royce Ltd., has been appointed Chairman of Napier Aero Engines Ltd.

A. J. Penn (*Fellow*), Technical Director of D. Napier and Son Ltd., has been appointed to the same position with Napier Aero Engines Ltd.

Sqn. Ldr. F. M. Prickett (*Associate Fellow*) formerly at the Air Ministry Directorate of Weapon Engineering, is now Senior Technical Officer, R.A.F. Misson.

Dr. J. S. Przemieniecki (*Associate Fellow*) formerly with Bristol Aircraft Ltd., Filton, Bristol, has been appointed Associate Professor of Aeronautical Engineering at the Institute of Technology, Wright-Patterson Air Force Base, Ohio.

D. K. D. Rees (*Graduate*) formerly Assistant Chief Aerodynamicist at Fairey Aviation is now Deputy Chief Aerodynamicist, Fairey Division of Westland Aircraft.

P. Ryan (*Graduate*) formerly with Westland Aircraft Saunders-Roe Division, is now an Aerodynamicist with Richardson Westgarth Ltd., Wallsend.

Rear Admiral G. C. Ross (*Associate Fellow*) formerly with Hawker Siddeley Aviation Sales Organisation, has joined the staff of Blackburn Aircraft Ltd., as Service Liaison Officer.

From Mrs. Florence M. Taylor—of Australia

The Society has received a letter from Mrs. Florence M. Taylor, widow of that eminent Australian Captain G. A. Taylor, which contains several diverting—and perhaps for some of the older members—nostalgic memories of the early days of aviation in Australia.

Mrs. Taylor, who had been O.B.E. for some years, was awarded the C.B.E. in the Birthday Honours List this year. She is 81 years of age and retired on 1st June 1961 from an active business life. For many years she was Editor of "The Australasian Engineer," "Building and Engineering" and "Construction."

In addition to taking an active interest in aviation—he was associated with Lawrence Hargrave—Captain Taylor was not only an artist and a journalist, but one of the earliest workers in the field of wireless telegraphy. A member of the Australasian Branch of the Institution of Aeronautical Engineers, he presented a medal to the Institution in 1926, which has been one of the Society's awards since the Institution was amalgamated with the Society in 1927.

The "George Taylor (of Australia)" Gold Medal is awarded for the most valuable contribution read before, or received by, the Society on Aircraft Design, Manufacture or Operation; among the recipients have been Captain F. S. Barnwell, R. K. Pierson, Sir Bennett Melvill Jones, Dr. G. V. Lachmann, A. Plesman, F. R. Banks, E. F. Relf, G. P. Douglas, Professor A. R. Collar, G. R. Edwards, R. E. Bishop and Walter Tye, to name a few only.

Captain Taylor died in 1928 but Mrs. Taylor has continued the medal and has indicated in her letter to the

Society that she hopes to provide for the medal to be awarded in perpetuity.

The following are excerpts from Mrs. Taylor's letter:—

"George Taylor had an aeroplane factory in Redfern in which he built planes (now called gliders) without engines in which he used to experiment to test the elements. He had the first aeroplane engine legal case in Australia for the non-delivery of an engine, which he lost as the judge said 'nobody in Australia could make an aeroplane engine.' But that did not stop George Taylor from trying.

"Mr. Leonard Schultz who became an Honorary Instructor in flying, and Sir Edward Hallstrom were among the youngsters who used to watch and help in his early flights at Narrabeen which attracted hundreds of people each week-end.

"I was the first woman to fly in a heavier than air machine, but 'being a precious mortal' they never let the guide ropes go and I flew only ninety yards in 1909. It was still a flight and was all good fun.

"As aeroplanes became fitted with engines and men really flew, George Taylor started an Aeronautical Society, or an Air Club or something to bring kindred interests together.

"I have no records, but Sir Charles Rosenthal told me he was a member when he was young. Sir Charles once got tangled up with some electric wires over a railway line with the trains passing every few minutes. This was about 1912 when planes had engines fitted to them. They were exciting times—all unrecorded, or nearly all, and very few are alive to tell the tale. We would leave home at 4 a.m. in an open Ford car without a hood on it, to get to Rose Hill Racecourse, where Harry Houdine, Bell Hart and many others flew.

"With all this fresh in memory, small wonder that I want to keep the name of George Taylor fresh when he contributed enthusiasm to the science and made everybody else enthuse."

Mrs. Taylor has written the letter herself in remarkably clear handwriting. With her letter she enclosed a printed circular which she had sent out to her many well wishers explaining why she had not answered their letters before. June 1961 was for Mrs. Taylor, as she says in the circular, a "momentous month." Not only did she receive the C.B.E., she retired in June and later that month suffered a severe loss in the death of her "life-long companion (my sister Annis L. Parsons)." Then Mrs. Taylor herself was seriously ill.

The Society congratulates Mrs. Taylor on her well-deserved honour, the C.B.E. and wishes her a complete return to health and years of happy retirement.

Astronautics and Guided Flight Section

A COMPARISON OF THE CONTROL PROBLEMS OF MISSILES AND MANNED AIRCRAFT

K. W. SMITH

To be given on 14th November

One of the main differences between manned aircraft and missiles is that in the former the "short period" dynamic characteristics should usually be at least moderately stable, while in missiles considerable instability can be tolerated.

However, this requires that missile control systems should have high gain "synthetic" feedback. Consequently, problems of stability associated with high gain are introduced which do not occur with such severity in manned aircraft. Typical missile stability problems, such as those arising from structural flexibility and propellant sloshing are dealt with in some detail.

Ballistic missiles, because they are required to operate in conditions where aerodynamic effects are sometimes negligible, need to utilise non-aerodynamic control forces. This introduces special problems, which only have a parallel in VTOL aircraft. The long duration altitude control on satellites in the presence of very small disturbances also presents a problem not encountered in the aircraft field.

The uncertainty of human pilot response is discussed in relation to the difficulties of adequate aircraft control system simulation.

Some remarks are also made regarding the interaction between control about various axes. These interactions are often fundamentally different between aircraft and missiles.

Seventeenth British Commonwealth Lecture

THE PROGRESS OF EUROPEAN AIR TRANSPORT 1946-61: WITH PARTICULAR REFERENCE TO BEA

Marshal of the Royal Air Force LORD DOUGLAS OF KIRTLESIDE

To be given on 16th November

The first part of the lecture will review the post-war development of air services in Europe and their emergence as an integral part of Europe's transport system. Lord Douglas will analyse their main characteristics and explain why traffic has grown in the manner and at the rate achieved. The financial status of European airline operations will be discussed and some suggestions will be made on how they could be made more profitable.

The second part will deal with co-operative developments in European air transport, in the fields of both governmental and airline activities. The lecturer will suggest that other parts of the world may have much to learn from European experience in co-operative endeavours.

In Part III Lord Douglas will describe the specific contributions which he believes BEA has made to the post-war development of European air transport. BEA has firmly established itself during this period as Europe's major regional airline and details of its experience are therefore a substantial part of the story of post-war European air transport. Moreover, the lecturer will show that in the technical field and in commercial matters BEA has played a leading part in the post-war development of the European airline industry. Air freight developments in Europe and BEA's future plans in this field will be discussed and reference will also be made to the post-war development of air services within the United Kingdom.

Finally the future of European air transport, including possible trends in the development of the aeroplane itself will be considered, in particular the prospects for air transport in the very short-haul travel market. Lord Douglas will conclude with some reflections on the nature of the contributions which the European airlines, and BEA in particular, may claim to have made to general progress of the air transport industry in the past ten years.

MILITARY USE OF GROUND EFFECT VEHICLES

W. H. COULTHARD

To be given on 21st November

The lecture illustrates, by typical examples, the standard of mobility which can be achieved by present military vehicles. An outline is then given of the mobility improvements which might be obtained by the use of military ground effect vehicles but, in the concluding section, emphasis is given to a number of generalised problems in the military operation of such vehicles which require detailed consideration before an adequate specification of ground-effect vehicles for military use is possible. The lecture deals only with vehicles which are designed specifically to exploit the ground effect principle and whose capabilities for sustained airborne movement are limited to the ground cushion; the emphasis is on vehicles for overland operation but some less detailed consideration is given to the more familiar problems of sea-borne operation.

FLIGHT CHARACTERISTICS OF THE B58 MACH 2 BOMBER

B. A. ERICKSON

To be given on 23rd November

The B58 is designed for strategic bombardment missions of intercontinental range at high subsonic speeds and sustained target dash at Mach 2.

Design of the aircraft is dominated by the stringencies of the Mach 2 capability. Of very small size for its type, the all-up gross weight exceeds 160,000 lb. Almost two thirds of this weight is fuel. High values of structural, aerodynamic and propulsive efficiency are attained. Arrangement of the aircraft's structure, systems and crew provisions are unusually compact, resulting in a configuration of extremely high density.

The B58 aerodynamic form is exceptionally clean and is tailless. The thin delta wing carries four turbo-jet engines underslung in individual nacelles distributed across the span.

A trapezoidal vertical tail is mounted far back on the fuselage. Two wing trailing edge-mounted elevon surfaces and a rudder comprise the total aerodynamic control surfaces employed. Structure of the aircraft is principally aluminium alloy, although steel and titanium are used in some high temperature areas. Bonded sandwich type construction is utilised extensively in the wing skin plates.

The crew of three, comprised of pilot, navigator-bombardier, and defence system operator, is located in tandem compartments. The B58 systems are highly automated.

A conventional type control stick is provided for the pilot. The flight control system is hydraulic powered and provides several features including "*g*" limiting, constant stick force per "*g*," automatic trim on the pitch axis, three axis damping, and a variety of automatic pilot modes. Optimisation of the aircraft systems in combination with the excellent provisions of the pilot's compartment provide a high level of "integration of pilot with machine."

High wing loading in combination with the low value of lift coefficient available from the delta wing require relatively high operating speeds for take-off, climb and cruise. Engine afterburners are provided for use during take-off and supersonic flight. Long range subsonic cruise is conducted at the threshold of drag rise. Elevator trim drag in the cruise condition is minimised by the effects of wing conical camber and the maintenance of small longitudinal static margin.

Supersonic dash at Mach 2 employs an intermediate afterburner power setting and provides steady climb in proportion to weight reduction from fuel consumption. The externally mounted weapon pod can be launched at any speed up to Mach 2.

Static and dynamic stability characteristics are of good quality throughout the flight spectrum. Low speed flight can be conducted to very large angles of attack without significant degradation of stability or control and is limited only by engine nacelle inlet requirements.

Stability and control are adequate for the accommodation of outboard engine thrust failure in all flight conditions, including Mach 2.

Manoeuvrability of the aircraft is excellent. Rolling manoeuvres are easily accomplished and are structurally limited by the strength of the engine nacelle attachments.

In strategic mission conditions the subsonic cruise as well as supersonic dash and weapon launch are accomplished under control of the automatic pilot, combined with the navigation-bombing system. The pilot in these conditions serves in the role of commander, monitor and adjuster of systems.

Rotorcraft Section

THE WESTLAND 192 HELICOPTER

A. McCLEMENTS

All-Day Symposium on 1st December

With the introduction of the Westland Belvedere to Service a milestone has been passed in the sense that it is the first twin-engined helicopter, and the largest, to be produced, *ab initio*, in this country. The lecture puts on record something about the requirement which led to the aircraft, the problems it posed, the aircraft which resulted, and some of the more important aspects of the philosophy on which the design was based.

The requirement is shown to be an imaginative one. Its significance is touched on and the problem it posed is defined. In solving the problem the tandem rotor configuration was chosen. The main reasons for this choice are given, and an attempt is made to examine their validity in the light of experience with the aircraft.

The aircraft itself is described briefly and reference is made to the method derived for stressing the fuselage, which was then novel and was later extended for more universal use.

The philosophy underlying the more fundamental aspects of the design is mentioned, and some of the resulting engineering solutions are described.

A film will be shown.

THE SIKORSKY CRANE HELICOPTER

PHILIP L. MICHEL

All-Day Symposium on 1st December

After many years of helicopter design, development, and operations a practical design of a flying crane is in construction which promises an unprecedented utility by virtue of the particular features embodied therein. The steps leading to this new helicopter configuration were evolutionary in nature and date back many years, even as far back as 1922 when the De Bothezat quadrotor machine hovered for one minute and forty-two seconds.

Historical developments are reviewed which added to the convictions on the part of many, both the military and in industry that a unique "crane" vehicle was needed at one end of the air transport spectrum, with an unusual "heavy lift" capability. Some highlights of early U.S. Army, Navy and Marine Corps experimental and operational experiences are discussed.

Various crane and high payload helicopter designs which were flown before 1958 are reviewed.

The present Sikorsky S-64 crane design represents a culmination of ideas and operational experiences stemming from U.S. Army and Marine Corps utilisation of the Sikorsky S-56 (Army H-37, Marine HR2S-1) helicopter. On the basis of far-reaching and comprehensive reports of these services and on the theoretical parametric studies, a philosophy was born whose merits were evaluated in a research vehicle designated the Sikorsky S-60 Skycrane. Events leading to the S-60 Skycrane and the specific knowledge gained in operation of this research vehicle are discussed. One of the most significant lessons learned was the importance of considering the complete crane system rather than the vehicle alone, in planning its application to a multi-purpose role. The importance of short "turn around time" in crane application to Army transport cannot be overlooked if maximum productivity and therefore a high mobility is to be achieved. To this end coupling of external loads must be accomplished rapidly and with a high degree of safety.

A general description including special features of the S-64 crane is presented in addition to performance characteristics, test schedule and some of the many applications, both military and civil.

The paper concludes with a discussion of possible future trends and discusses some of the important design parameters and the manner in which these may be influenced by technological advances. Areas for further research are discussed.

Astronautics and Guided Flight Section

MILITARY DESIGN REQUIREMENTS OF GUIDED MISSILES

Brigadier E. W. DENISON

To be given on 12th December

The lecture is based partly on the lecturer's past experience and partly on his present position in de Havilland.

The initiation of new missile projects in the U.K. is done by a system which is the result of past history. The post-war developments were based on long-term advances. There was no attempt at a step-by-step progress. Under the present system the Service User thinks up a new requirement, adds everything he knows and combines every other use, then puts in every NATO requirement. The result is so complicated that no result can come out for years. In the meantime we buy foreign, accepting something much less. The more recent tendency to do proper design studies, before embarking on a real development, is a healthy one. An alternative to this system is for the firms to do Private Ventures. If a firm does accept the official development, it must have real confidence in it.

Turning to the technicalities of military guided missiles, accuracy figures should be discussed. Guided missiles are in the forefront of known techniques: great expense in the missile may lead to accuracy or reliability which makes the expense well worthwhile. Some curious anomalies in Service Packaging of missiles may be mentioned.

Design for reliability is a subject which should be expanded. Discovering the conditions of transport and firing is a major problem, which will be discussed and illustrated. A description (with slides) of the de Havilland Environmental Testing facility will be given.

There is a particular problem of certain missiles which must combine extraordinary safety with acceptable reliability. Clearly the fuzing systems for missiles are a unique problem, and it is hard to think of a civilian parallel. Without disclosing anything of a classified nature, it must be obvious that the requirements can be achieved by duplication and redundancy of apparatus. A slide illustrates the way in which duplication, or paralleling of apparatus can be used to provide an extraordinary degree of safety together with reliability.

The Journal of the Royal Aeronautical Society

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

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EDWARD RAYMOND SHARP

Sc.D., D.Eng., F.I.A.S., F.R.Ae.S., F.C.A.I.

AN APPRECIATION

DR. EDWARD RAYMOND SHARP died at his home in Cleveland, Ohio, on the 24th July 1961. He died after some months of suffering which he had borne with great fortitude. His passing is mourned by all who knew him.

Ray Sharp—as he preferred to be known—was born in Virginia 67 years ago and graduated in Law at Williamsburg. He served in the U.S. Navy in the First World War and, as a Lieutenant, did escort duty in the North Atlantic and the Mediterranean. When he retired from the Naval Reserve as recently as 1942, he held the rank of Lieutenant Commander.

In his work, Dr. Sharp was best known as the Director of the Lewis Research Center of the National Advisory Committee for Aeronautics now renamed the National Aeronautics and Space Administration. He joined the N.A.C.A. in 1922 at the Langley Aeronautical Laboratory in Virginia, becoming Administrative Officer. In 1940 he assisted in building for the N.A.C.A. the Ames Laboratory in California. A year later he transferred to Cleveland and became Manager during the reconstruction of the Lewis Laboratory. He was appointed its Director in 1947 and held this position until his retirement at the end of 1960.

The Lewis Research Center is primarily concerned with matters of propulsion and was initially built with equipment for the testing of piston engines and propellers that was second to none. With the coming of the gas turbine, this equipment was extended and modified to embrace the new requirements in terms of capacity, altitude and equivalent air speed. Then, with advancing speeds came the ramjet and the rocket and the transition from air-breathing engines to the propulsion of vehicles in space. And finally, for this latter purpose came the use of nuclear energy and the creation of an entirely new facility still to be administered from Cleveland.

In all this work Dr. Sharp showed great powers of originality and adaptation so that great strides were made without scrapping what had already been created.

In recognition of nearly 40 years service with N.A.C.A./N.A.S.A., Dr. Sharp was given the title of Director Emeritus of the Lewis Research Center in March 1961. Numerous distinctions and awards were made to Ray Sharp in the course of his career, but one he treasured most highly was the N.A.S.A. Medal for

Outstanding Leadership. The citation accompanying this medal so aptly summarises his contribution at Lewis that it is repeated below:—

> "This signal honour has been made because you have demonstrated outstanding leadership throughout your career, in the maintenance and improvement of research operations during agency growth; in the training of men to meet the agency needs for critical skills, ranging from the apprentice crafts and trades to the major technical and executive levels; in the development and growth of aeronautical and space research facilities which enabled the Lewis Research Center to meet critical military objectives in World War II and in the administration of the propulsion research programme at the Lewis Research Center."

In this Country, Ray Sharp was known to a wide circle of friends but especially to the engine people whom he had helped and made welcome in Cleveland

on numerous occasions. Not only did he and his colleagues smooth away our technical difficulties but he made each and every one of us feel so completely at home by taking us into his heart and smothering us with the inspiration, enthusiasm and kindness that were the very essence of Ray Sharp.

Many of us remember Ray at various international aeronautical conferences which he keenly supported. We remember with affection the welcome he gave us when the delegates to the Anglo-American Conference visited Cleveland in 1959. After the heat, bustle and rather impersonal existence of a week in New York, we were made to feel that we were indeed once more members of a family. A few of us who attended the Second International Congress in the Aeronautical Sciences in Zurich in September 1960 vividly recall a pleasant afternoon's cruise on the Lake with Ray, his wife Vera and other friends: we little knew this would be the last occasion. Only in March last he wrote to the writer from his bed of sickness saying he had had a lung removed, was recuperating at a very fast rate and his summer plans were simply the Anglo-American Conference, Farnborough and a nice trip to the Continent. He was a man of very great spirit and unquenchable cheerfulness.

Dr. Sharp was President of the Institute of Aeronautical Sciences in 1956 and had supported its activities throughout his working life. He was a member of the Society of Automotive Engineers, a Fellow of the Canadian Aeronautical Institute and, interestingly, a member of the Newcomen Society. He was elected a Fellow of the Royal Aeronautical Society in April 1959. His lively interest in our members and their activities did much to cement good Anglo-American relations in the field of aeronautics. He would speak with pride of "our Society" and he meant it.

Wonderful tributes have been paid to Ray Sharp by his colleagues and associates. In this connection we would mention particularly Dr. Hugh Dryden, Dr. Abe Silverstein and the Acting Director, Eugene Manganiello. At this time, however, our thoughts are especially with his widow and his family of two sons and a daughter. Those of us who had the good fortune to know Ray Sharp and whose lives were made the richer thereby extend to them our sincere sympathy in a great loss to us all.—E. S. MOULT.

The Agena Satellite and The Discoverer Programme

BY

RONALD SMELT, M.A., F.R.Ae.S.

(Chief Scientist, Satellite Systems, Lockheed Missiles and Space Division)

1. Introduction

The history of the Agena space vehicle starts in the years immediately following the Second World War, when the Rand Corporation under a contract with the U.S. Air Force examined the potential applications of satellites, recognising their technical feasibility as an additional bonus from an inter-continental ballistic missile development programme. The U.S. Air Force kept this concept alive throughout the development phase of the ICBM programme; the Lockheed Aircraft Corporation actually received its first contract, for detailed engineering studies, in 1955. The Agena space vehicle has grown from these beginnings and is now the vehicle selected for a large variety of U.S. space projects. Most of these are satellites, but they include a few space probes and moon explorers.

In this respect, members of the Royal Aeronautical Society will recognise with pleasure a trend back to the versatility of the aeroplane, in marked contrast to the narrow single-mission capability which has marked the past decade of missile development. To illustrate this point, we can draw a parallel with famous aircraft, such as the Spitfire or Mosquito, in the Second World War. The variety of missions in which these aircraft performed well is remarkable; they were night fighters, day fighters, photo-reconnaissance vehicles, "path finders," fighter bombers and carrier-based aircraft. They contributed also to the scientific field; the Spitfire helped considerably in unravelling the problems of transonic flight, and became almost the accepted standard at the Royal Aircraft Establishment for performance investigations involving such matters as surface roughness or engine modifications. In general, in such aircraft we look for qualities of performance, control, and dependability which are more basic than the specific requirements for a particular mission.

In exactly the same way, our objective in Agena development has not been primarily to satisfy a specific mission in space, but to produce a vehicle whose basic capabilities lend themselves to many space applications already being explored, and probably to many others not yet conceived. The basic requirements are analogous with those of the earlier aircraft. In place of aircraft performance we require load-carrying capacity, a capability which depends not only upon the lightness and efficiency of the structure and the specific impulse of the power plant, but also upon the precision with which the vehicle executes required trajectories; as an example, any margin of error during ascent into orbit represents additional fuel weight to be carried as a contingency. The aircraft requirement for simple, effective control is present in the satellite too. Many missions require it to provide a stable flying platform, while others, particularly those requiring recovery from orbit, demand precise programming and timing. Finally, the third quality of dependability becomes all-important when the vehicle and its equipment must function without attention for periods of days or even months on orbit.

The Discoverer programme has offered an excellent opportunity to develop the Agena vehicle into a versatile satellite. Originally the Agena vehicle was planned to utilise only an Atlas booster. It was recognised in 1957 that by the use of the Thor missile, then at a much more advanced stage than Atlas, it would be possible to make earlier orbital experiments. Although the lower performance of Thor as a booster greatly reduced the carrying capacity of the vehicle, it still offered the possibility of providing earlier engineering data from the basic vehicle. The Discoverer series was introduced in this way; and flights during the past two years have permitted the engineering development of the vehicle, its precise injection into orbit, and its stabilisation and command, to be greatly advanced. It has also been possible to experiment with all three of the techniques which will provide scientific and engineering data from the vehicle: by direct observation from the ground, by telemetering from the satellite, and by recovery of physical components out of orbit. In this short paper it is only possible to select a few specific examples of data obtained by each of these techniques. These will serve, however, to illustrate the major features of the vehicle and its associated ground tracking and control system. Before discussing typical flight results, a brief description of the Agena vehicle will be provided. Some details have already been given in recent publications[1,2] and are summarised in Section 2.

2. Details of the Agena Vehicle

2.1. GENERAL DESCRIPTION

In its application to the Discoverer programme, the Agena satellite combines the orbital equipment with the engine and fuel for the last stage of ascent boost. The entire vehicle (Figs. 1 and 2) is placed in orbit. Much of the internal space is taken up by fuel and oxidiser tanks. Fig. 3 shows how the two tanks are combined into a single unit in the original Agena A vehicle; the tanks of

The 15th lecture to be given before the Astronautics and Guided Flight Section of the Society—on 18th May 1961.

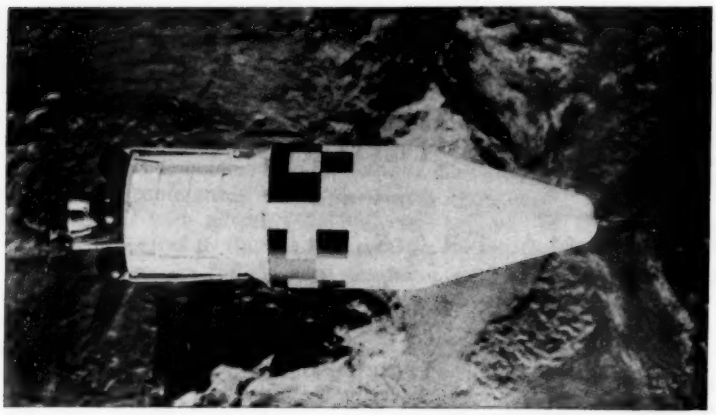

FIGURE 1. Photograph of Agena A.

Agena B are larger. and have been made integral with the outer skin. Equipment racks are located in the nose section of the vehicle and also aft of the tanks around the engine compartment. These contain the power supplies and much of the radio and control equipment. In addition, for those flights in which recovery of experimental equipment from orbit is planned, the nose of the vehicle contains a separable capsule with a retro-rocket, heat shield, and other devices required to permit it to re-enter from orbit. The radio equipment, some of which is duplicated in the re-entry capsule, includes beacons to assist in tracking, telemetering equipment relaying engineering and performance data back to ground stations, and receiving equipment for commanding changes on orbit.

2.2. INTERNAL POWER SUPPLY

For the Agena power supply a silver peroxide-zinc primary battery is incorporated as the prime energy source. This battery was developed specifically for satellite operations and incorporates refinements for high efficiency and performance in zero-gravity environmental conditions. For Agena applications in which months of operation on orbit are envisaged, the battery reservoir is recharged by a solar collector. In the Discoverer series the planned duration of the experiment is only a few days, so that the batteries carry sufficient power without the added complications of recharging. Most of the battery power is converted to a.c. before distribution, simplifying the supply of different voltages to the various equipment, and minimising any effects of coupling of a d.c. current loop with the earth's magnetic field. Static inverters with power transistors are used throughout, in preference to rotating converters with possible lubrication problems and inertial effects upon the stabilisation equipment.

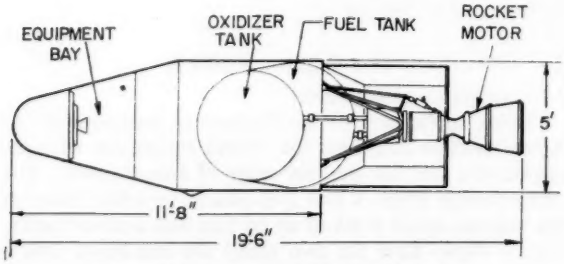

FIGURE 2. Agena A—Overall dimensions.

2.3. ROCKET MOTOR

A pump-fed liquid rocket motor developed by the Bell Aircraft Company is used in all Agena vehicles. It was selected largely on the basis of reliability, having had an unusually large number of development runs, and it has amply justified this selection by a remarkable record of never having failed to start in flight when required. Furthermore, its potential for further performance improvement is considerable. It has already permitted a change of fuel from JP4 to UDMH, and a number of nozzle modifications, all increasing its specific impulse. In the Agena B it has incorporated a multiple restart capability. In this continuing engine development programme, we again note a parallel with development practice in aircraft engines. The large engine test facilities at AEDC, Tullahoma, have been invaluable in this development, permitting full operation under vacuum conditions in the laboratory.

2.4. STABILITY AND CONTROL

Probably the simplest way of stabilising a satellite vehicle is to spin it, and a number of early satellites have used this technique, at least during the final stage of

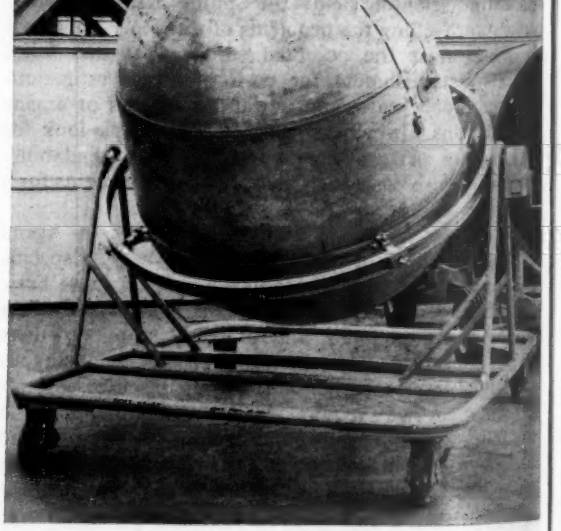

FIGURE 3. Agena A fuel tank.

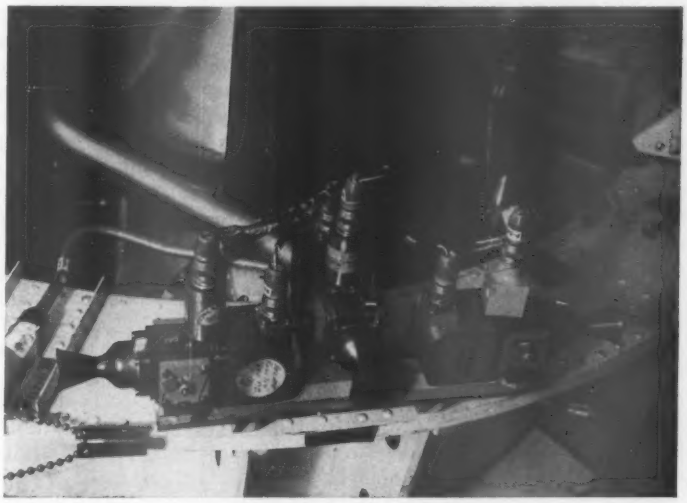

FIGURE 4. Jet Controllers.

ascent acceleration when it is necessary to orient the thrust direction accurately. Of course, this method of stabilisation locates the satellite along a specific direction in space, whereas for many "down-to-earth" applications it is preferable to locate the satellite relative to the local vertical. Agena's stabilisation system can maintain its position relative to the local vertical while at the same time permitting its attitude in this co-ordinate system to be modified at will by command. The system depends upon attitude information supplied by three orthogonal position gyros. Their signals, combined in conventional manner with rate information from three orthogonally-mounted rate gyros, are used to control the vehicle attitude through two alternative control systems. In Discoverer vehicles when coasting (during ascent or on orbit) the error signals actuate cold gas reaction jets through specially designed proportional gas valves. Fig. 4 shows the assembly of three such jet controllers on one side of the vehicle; there is a corresponding unit on the other side. The jets are fed by a mixture of dry nitrogen (N_2) and tetrafluoromethane (CF_4) stored at high pressure in a titanium sphere. The pitch and yaw moments provided by this control system, although adequate for coasting flight, are not designed to overcome the asymmetry of the main rocket motor during powered flight. They are therefore locked out when the main motor is operating, and pitch and yaw control is then obtained by two hydraulic servos moving the main engine nozzle.

The direct actuation of gas jets for control is somewhat expensive in gas supply, but its basic simplicity recommends it for short-life operation as in the Disoverer series. For durations of many weeks on orbit the gas jets can be supplemented by a fine control which does not use gas; for example, by the modulation of a fly-wheel. Such a system requires the gas jets to be brought into action only when the fly-wheel speed goes outside its designed limit.

Manoeuvres of the vehicle are commanded by torquing the position gyros. In particular, the continuous change in orientation in space required to maintain a fixed reference relative to the local vertical is obtained by applying a continuous torque corresponding to a rate of pitch of about 4° per minute on Discoverer (the typical low altitude orbit of Discoverer has a period slightly greater than 90 minutes).

This steady rate of pitch of 4° per minute is only a rough approximation to the required pitch rate. To provide accurate location relative to the local vertical in pitch, and also to compensate for the drift in all three gyros of the inertial reference package, a continuous indication of the local vertical is provided by a horizon scanner. This infra-red device senses the position of the horizon, during both day and night, and its error signals in pitch and roll are applied to correct the positions of corresponding gyros of the stabilisation system. To measure the deviation in the third (yaw) axis, the steady pitch rate of 4° per minute due to the stabilised motion in the plane of the orbit is utilised. Any deviation in yaw causes a component of this angular velocity to appear in the roll axis, and roll error signal from the horizon scanner can thus be used directly to correct the yaw gyro.

2.5. LAUNCH

All Discoverer vehicles have been launched from Vandenberg Air Force Base on the California coast; the near-polar orbits which are possible from this launch point simplify regular contact with the vehicle from a limited number of ground stations. As shown in Fig. 5, the injection of a Discoverer into orbit can be divided into three phases. In the first phase the Thor booster delivers the Agena vehicle into a trajectory with apogee equal to the required injection altitude. Upon separation of the Agena from the Thor booster, the second (coast) phase begins. The stability and control system provided for orbit attitude control is immediately brought into action to align the vehicle so that its axis is horizontal, ready for the application of final boost. During this coast phase the radar track of the first phase is being analysed by a computer at the launch point to determine

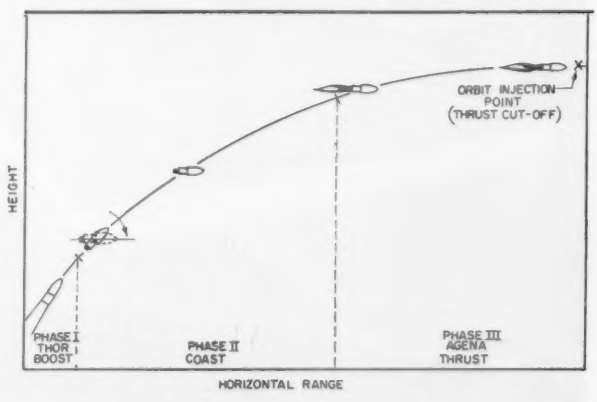

FIGURE 5. Discoverer ascent trajectory.

the actual performance of the Thor booster; from this data, instructions are transmitted to the Agena vehicle defining the time to ignite its engine, and the velocity increment required in the third (thrust) phase. This velocity increment is measured accurately by an integrating accelerometer of the type developed in the ballistic missile programme. The objective of the radio commands is to arrive at the correct injection velocity with high precision, at the same time as the inclination of the flight path has reached the horizontal, at the original Thor apogee height. This injection point at the end of the third phase then becomes the perigee of the resulting satellite orbit.

The multiple-restart feature incorporated in Agena B permits a further phase to be introduced to achieve high-altitude near-circular orbits. In this technique the satellite orbit selected at the end of the third phase is highly elliptic with its apogee height equal to the final desired altitude. When this apogee is attained, the engine is restarted. A short burst of thrust, only a small fraction of the original impulse in the third phase, then suffices to convert the elliptic orbit into a circle. The only practical difficulty in this technique lies in observation of the final injection point, which requires a tracking station about half-way around the earth from the launch point.

3. Discoverer Observations from Ground Stations—Geophysical Results

In the last section mention was made of the tracking radar equipment which supplies instructions to the motor of the Agena satellite. Assisted by a beacon in the satellite, which also acts as a command receiver, this equipment gives position information throughout launch up to the point of cut-off of the Agena motor—the "injection point." Since the satellite is then about 1,000 miles south, and almost on the horizon, the tracking data at this point is not very precise. It is adequate, however, to give all the ground stations information on the time and position at which they should expect the vehicle to appear. Analysis of the tracking data, and its conversion to information in the co-ordinates of the individual ground stations, must be done in the short time available before the satellite appears at one of the tracking points. This analysis is performed in the U.S. Air Force Satellite Test Center (Fig. 6) adjacent to the Lockheed plant at Sunnyvale, California. Throughout the flight the Satellite Test Center acts as the control centre for all vehicle information and operations. It is also responsible for integration with the scientific community, and maintains continuing contact with the U.S. Space Track Headquarters at Cambridge, Massachusetts. The Space Track net is furnished with vehicle orbit prediction, and in turn feeds its observations on the satellite into the Satellite Test Center. In this centre two large-scale electronic computers operate in parallel to provide orbital calculations, with complete duplication of peripheral equipment in the interest of reliability.

The first really precise orbital data is provided by a station strategically located on Kodiak Island in Alaska (Fig. 7) almost at the end of the first orbit. Subsequently, as the orbital plane moves westward relative to the rotating earth, other stations pick up the vehicle and the electronic computers continually up-date the orbital information and inform the ground stations. In addition, command functions for the timing of events in the vehicle are developed by these machines on the basis of the orbital data. By the end of the second orbit the vehicle's path and future history are usually firmly established, and the complete experiment is mapped out; including the selection of point of recovery for those experiments which include return of a capsule from orbit.

After about one and one-half days of intense activity (on Agena A) including much telemetering, the vehicle exhausts its control gas supply and changes from stable to tumbling flight. All Discoverers subsequent to No. XV have utilised Agena B, and the extra load-carrying capacity then permitted stable flight for longer periods, up to four days. The beacon electrical supply usually lasts much longer; when it is exhausted, tracking by Discoverer stations is discontinued and vehicle monitoring then becomes the functions of the skin-tracking radars of the Space Track organisation.

Apart from its direct use in monitoring the satellite, the tracking data obtained during this operation has more general scientific value in geophysical and geodetic work, and we are steadily improving its accuracy by the introduction of new techniques, including optical tracking and doppler methods. The example chosen here, of density measurements in the upper atmosphere, may be of particular interest in view of the major contributions which Dr. King-Hele and his colleagues at the Royal Aircraft Establishment have made in this field[3, 4].

FIGURE 6. Satellite Test Center at Sunnyvale, California.

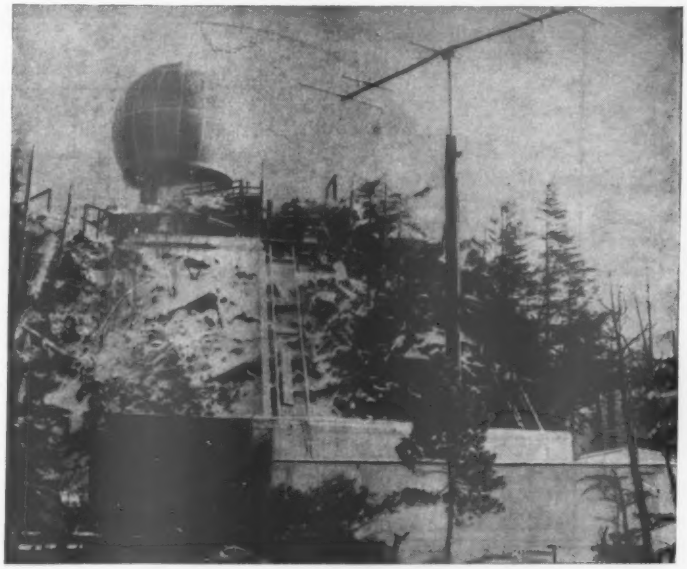

FIGURE 7. General view of Discoverer station at Kodiak, Alaska.

Most of the Discoverers have been intentionally launched a few degrees east of polar, so that the perigee moves slowly northwards with time from its initial position near the injection point, under the influence of the earth's oblateness. A peculiar feature of the orbital period P then appears in our results; the rate of decay $(-dP)/(dt)$ decreases with time, whereas since the satellite is gradually moving down into denser air, its decay rate should be gradually increasing. The effect is only small, and needs high precision to measure it, but the negative curvature can be seen clearly in the Discoverer VII decay curve on Fig. 8. I have concluded that this effect arises from a steady decrease in density as latitude increases, at the same geocentric distance.* The magnitude of this decrease is shown in Fig. 9, in which results from several Discoverers are expressed as the ratio of density (or dP/dt) at any latitude to its value at 45° latitude, at the same geocentric distance.

The reason for this steady decrease in density with latitude is straightforward. If the satellite perigee moves north at constant geocentric distance, then its actual distance from the earth's surface increases because of the earth's oblateness. The full line on Fig. 9, which gives a good mean of the experimental results, is in fact a calculated curve assuming that the atmospheric density profile remains unchanged with latitude, relative to the local earth's surface. The real interest in this result is that it differs considerably from the results of earlier rocket soundings over the same range of altitude, around 170 to 220 km; here it should be noted that the Discoverer flights are at the lowest altitudes achieved by satellites, and overlap appreciably the earlier rocket experiments. Density data from these experiments are shown in Fig. 10, which is taken from Ref. 5. The wide variation in the results has been interpreted as implying order-of-magnitude changes in density with latitude and time. The Discoverer results, on the contrary, define an atmosphere which is substantially independent of latitude, to the order of accuracy of the data, *i.e.*, about 4 per cent. Furthermore, there is no evidence in our data of large changes with time. The points of Fig. 11, obtained from Discoverers VI to XI, define a remarkably good density-altitude curve although they were obtained

*The orbital data summarised here is presented in detail in a thesis by the author, Stanford University 1961.

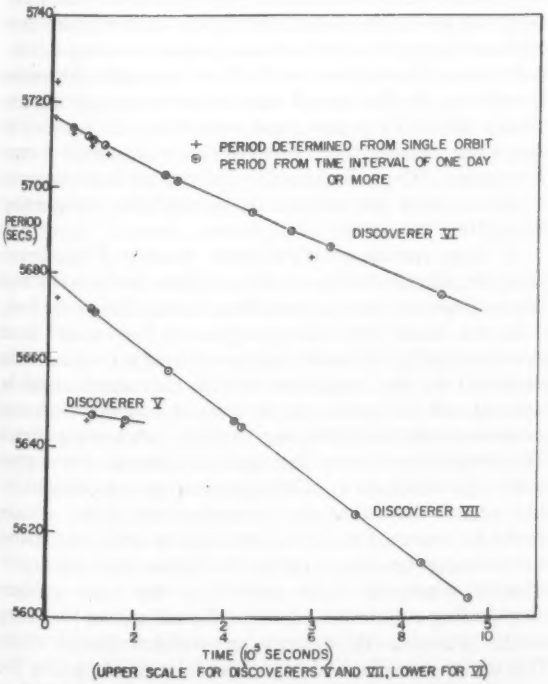

FIGURE 8. Decay of period, Discoverers V, VI, VII.

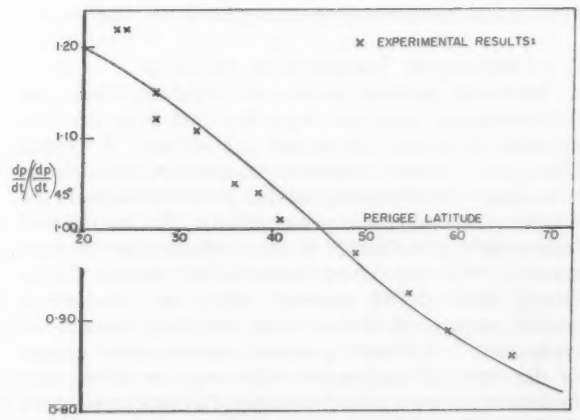

FIGURE 9. Experimental data on variation of decay rate with perigee latitude; and comparison with expected variation for constant atmosphere, oblate earth.

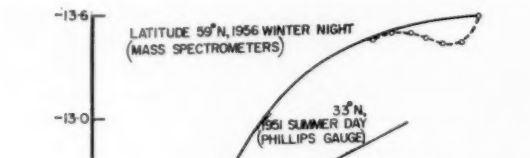

FIGURE 10. Atmospheric density from sounding rocket data.

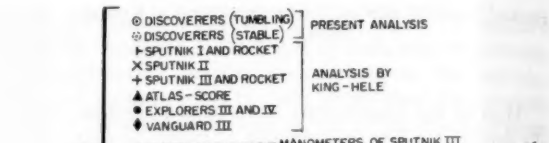

FIGURE 11. Atmospheric density derived from Discoverers, and comparison with other satellite data.

over a time interval from August 1959 to April 1960 (with the perigee in daylight throughout). It is interesting to note in Fig. 11 the manner in which the Discoverer data extrapolates smoothly to lower altitudes the Russian results derived from direct ionisation gauge measurements on Sputnik III early in 1958. The other points scattered around these combined curves are from the collection of satellite data by King-Hele in Ref. 4.

The continuing Discoverer flights, with increasing precision, should add more detail to the study of the atmosphere at the lowest satellite altitudes, where we are most interested in accurate density information. We would particularly like to examine whether the data changes with solar activity during the eleven-year solar cycle, or whether there is a significant influence of a solar flare. A preliminary examination of density data from Discoverer XVII, which was up in the strong solar flare of 12th November 1960, suggests such an effect, but this will be reported more completely in a later paper.

4. Discoverer Telemetered Results

By far the greatest quantity of orbital information in the Discoverer series has been obtained from the telemetering equipment on board the vehicle. A typical Discoverer carries sufficient telemetering equipment to transmit 150-200 individual data points throughout the lifetime of the electrical power supply. The telemetered information is collected at every Discoverer tracking station. The techniques employed at present follow closely the FM-FM systems* which are standard in missile range work in the U.S.A., although the satellite equipment is a densely packaged subminiature version of the standard equipment. The majority of the telemetered channels are used to indicate correct or incorrect functioning of individual components; for example, they monitor gas pressure, power supply voltage, horizon scanner error signals, and so on. Thus they contain primary engineering design information, uninspiring to the scientific research workers but vital to the practical satellite designer as verification of his design assumptions.

In an earlier paper[1] some of the surprises which we have encountered in this engineering data have already been discussed. For example, the pressures which are measured inside the instrument space in the Discoverer series are larger by orders of magnitude, in early orbits, than the ambient values in the high atmosphere outside the vehicle. At the end of the first orbit, the pressure is usually about 10^{-3} mm, and even after 25 orbits (38 hours) the pressure does not fall below about 10^{-5} mm of mercury. It appears that most of the surfaces exposed to the vacuum are subject to appreciable out-gassing during the early orbits.

A more serious problem arose in early Discoverers when the temperatures at various points in the skin and structure were measured on orbit. In the design we had, of course, made extensive analyses of the radiant heat balance on orbit. A small amount of heat is continuously generated by the equipment inside the vehicle, and is radiated out to space. In reverse, the vehicle receives radiation from neighbouring surfaces, absorbing about 450 watts/metre^2 from the sun, and about 200 watts/metre^2 from the earth. Detailed heating calculations of this type showed that on near-polar orbits the vehicle would be expected to cool down appreciably. To avoid this, coatings having a high ratio of solar absorptivity to infra-red emissivity were applied to the outer surface surrounding equipment regions, in such a way that they would provide, on balance, a uniform temperature. This design was checked experimentally by mounting the vehicle's front end with operating equipment in a

*A method of radio transmitting wherein the signal is frequency-modulated on a sub-carrier wave, which in turn is frequency-modulated on a carrier wave.

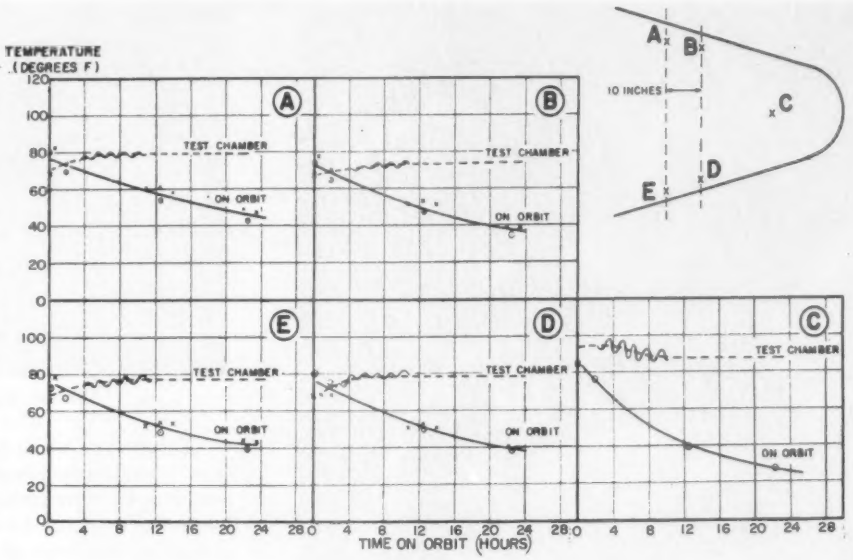

FIGURE 12. Temperature distribution, test chamber and flight.

Lockheed vacuum chamber designed to provide radiation simulating the flight conditions. Fig. 12 shows test results at some representative points, confirming the design for a constant temperature of about 80°. The figure shows also the large discrepancy found in the data from orbit; in some regions the temperature actually fell below freezing point after a few orbits. We have traced this discrepancy to changes in the surface radiation properties resulting from heat during the ascent to orbit. In the short-life Discoverer vehicles, it proved easy to correct the temperature conditions by a simple electric heater and thermostat, drawing power from the main battery described in Section 2.2. In longer-life applications of the Agena vehicle, this wasteful use of battery power is not acceptable, and we have therefore done considerable development work to provide a selection of coatings with desirable radiation properties which can withstand the ascent temperatures.

5. Recovery of Orbital Equipment by Capsule, with Some Results

Undoubtedly the most difficult method of obtaining orbital information is to bring back physical equipment or data records to earth; we have, however, applied a considerable fraction of the Discoverer effort to this particular problem, since recovery of components and data in this manner offers the opportunity of a far more complete diagnosis than either of the alternative information-gathering techniques. Furthermore, the recovery of physical parts of the satellite in this way is an obvious step towards manned orbital flight; to quote Lt. Gen. Bernard A. Schriever, "Until we could do this, we were only partially on the road to space." Development of recovery techniques has therefore been included as a part of the experimental programme of most of the Agenas of the Discoverer series. Presumably because of its obvious connection with man-in-space, this part of the programme has generated wide interest. The design of the recovery capsule (Figs. 13 and 14) to withstand the heating and decleration during the descent is an extension of the problem of re-entry from a ballistic missile trajectory, and was subcontracted to the General Electric Company, a leader in the missile re-entry field.

The general principles of hypersonic re-entry into the atmosphere are now well understood and have been discussed in a number of papers. Essentially, there is a "corridor" in the velocity-flight path relation, on the one side of which the deceleration becomes excessive; this is a very significant criterion when biomedical limitations must be met. On the other side of the corridor the total heat absorbed during re-entry is too great, so that the heat protection provisions become unacceptably heavy. The problem in the satellite is to apply a small retro-velocity to the capsule with magnitude and direction selected to put the vehicle well inside this corridor. A second problem is to arrange the timing of the ejection process from the satellite, and the subsequent capsule trajectory, so that the expected margins of error would give final recovery inside a small prescribed recovery area, actually a rectangle. This problem is simplified by the fact that there is an optimum initial attitude of the Agena vehicle, about 60° nose-down, which minimises dispersion due to incorrect vehicle attitude.

The recovery sequence (Fig. 15) begins with this nose-down movement, initiated at the appropriate position on orbit by torquing the pitch gyro, as described in Section 2. Separation of the capsule then occurs, the retro-rocket delivers the required impulse, and the capsule then coasts until it reaches the sensible atmosphere. Drag and heating effects become significant at about 350,000 ft. In this region the heat shield which protects the capsule attains a surface temperature of about 4,000°F, but insulates the interior by "ablating." The deceleration during this phase reaches a maximum slightly over 10 *g*, slowing the capsule so that at about 50,000 ft. altitude a parachute can be opened.

At this point the U.S. Air Force brings into operation its "air snatch" system (Fig. 16). It was chosen as the primary method, in preference to sea pick-up, because of its relatively high flexibility in responding to last-minute or unplanned changes in recovery point, which can easily involve thousands of miles of movement. The entire air snatch operation can be practised by the use of capsules dropped from high-altitude aircraft; by such methods the picked U.S. Air Force crews have developed the technique to the point where the probability of success is extremely high—over 95 per cent—when the capsule and parachute appear in the target area.

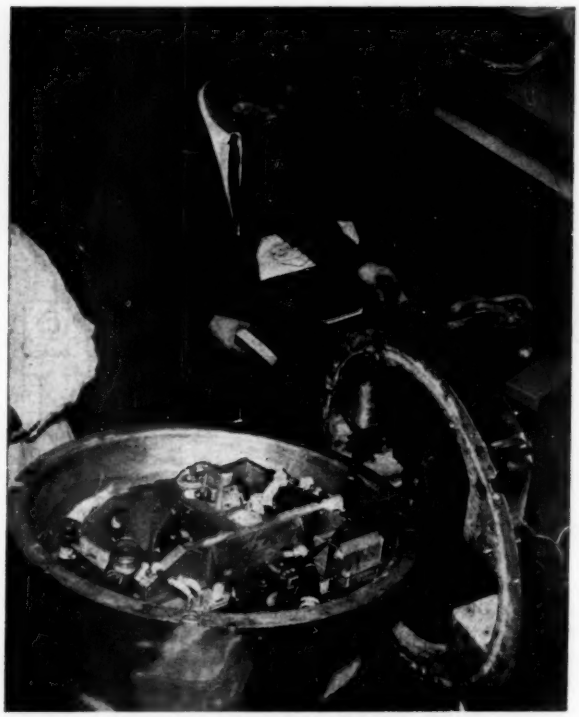

FIGURE 13. Capsule of Discoverer XIII.

A backup sea recovery force is also present in the target area, and has been successful on one occasion—on the first successful recovery of the capsule from Discoverer XIII on 11th August 1960. The first successful air snatch, of the capsule in Discoverer XIV, occurred one week later. It was followed by two disappointments. Discoverer XVI was the first Agena B launched, and gave mechanical trouble; previously Discoverer XV had functioned perfectly throughout the flight, but delivered its capsule (re-entering successfully) well outside the target area in rough seas, so that it sank before it could be picked up. Discoverers XVII and XVIII were completely successful, and their capsules were air-snatched after two and three days respectively of controlled stable orbit. Following these successes the Discoverer programme then changed to another phase in which recovery was not required.

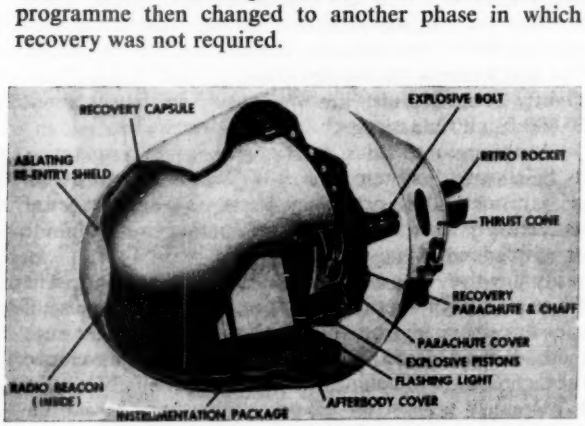

FIGURE 14. Capsule Cutaway.

FIGURE 15. Recovery Sequence.

Discoverer XVII, launched on 12th November 1960, was particularly interesting in that it flew through a major solar flare (magnitude 3+), and I have therefore chosen the results from this flight as an interesting example of the type of data which can be obtained by recovery techniques. The flight actually began about seven hours after the flare was first detected by ground stations (neutron count monitors) and continued for 2·075 days (31 orbits) before the capsule was recovered. Rough estimates from the data provided by these ground stations indicate that while the vehicle was in orbit about 50 per cent of the total flux of high energy protons, greater than 1 Bev*, from the flare occurred. The lower energy protons reached maximum flux at the earth several hours later than first observations, so that the satellite was exposed to about 90 per cent of the total proton flux with energies less than 150 Mev†. It is estimated that the capsule's skin and heat shield effectively shielded the instruments inside from proton radiation with energies less than 30–50 Mev. In a paper recently published by Dr. Yagoda[6] the conditions during the flight are described in more detail. Fig. 17, taken from this paper, shows the manner in which the flux varied during the flight, as deduced from balloon data and Explorer VII observations. From this data it can be deduced that the satellite received a total bombardment of about 10^9 particles/cm^2.

Experimental equipment for the capsule furnished by two U.S. Air Force laboratories, the Geophysical Research Directorate at Bedford, Massachusetts and the School of Aviation Medicine at Brooks Air Force Base in Texas, give the most interesting data from the flare. Both laboratories provided essentially similar equipment for the flight one month later of Discoverer XVIII.‡ The Geophysical Research Directorate experiments and their results are described by Dr. Yagoda[6]. In summary, they showed that the flux of the heaviest primaries was substantially unchanged during the flare, as might be expected from their galactic origin. The solar

*Bev=*B*illion *e*lectron-*v*olts.

†Mev—*M*illion *e*lectron-*v*olts.

‡Discoverer XVIII's capsule was recovered after 48 orbits, and incidentally was caught in the air by the same pilot, Captain Gene W. Jones, who made the mid-air catch of Discoverer XVII's capsule.

FIGURE 16. Air snatch.

flare bombardment appreciably increased the radio-activity of the metals in the capsule. In particular, an analysis of iron and lead samples by the Smithsonian Observatory revealed an extremely high tritium content; the iron actually contained over 500 times more tritium than would be expected from the normal action of cosmic rays. On comparing the average tritium production rate on orbit (150,000/Kg. min.) with that of argon 37(58/Kg. min.) it is deduced that the extremely large tritium content, rather than being generated by bombardment, appears to result from tritium in the flare itself.

The experiments of the School of Aviation Medicine were essentially biomedical in nature, and a preliminary description has been given by Dr. Crawford and Maj. Davis[7]. Their equipment in the capsules of Discoverers XVII and XVIII included a large number of dosimeters of different types (chemical, film packs, foils), and in addition, biological specimens including cell culture and gamma globulin, bacteriological spores and algae. The dosimeter data indicated that the interior of Discoverer XVII's capsule was subjected to a total dose of 30–100 rads (for 730 Mev protons); the equivalent flux is calculated to be about $6\text{–}8\times10^8$ protons/cm^2. In contrast, the dosimeters of the Discoverer XVIII capsule gave only a bare indication of radiation, well below 1 rad. Neutron and electron bombardment were quite small in both flights.

The biological specimens generally showed little effect of the radiation field in Discoverer XVII. The algae were not adversely affected in any detectable manner by their exposure. They exhibited very stable genetic characteristics on their return. There was degeneration in the human cell cultures, but similar mortality rate in the ground control cultures appears to imply that exhaustion of nutrient, rather than radiation, was the real difficulty.

In summary, the radiation dosage measured on Discoverer XVII, and the behaviour of the biomedical specimens which it carried, give us considerable confidence in the ability of man to survive a solar disturbance if by chance it should occur during a manned space flight.

6. Long Life in Space

Sections 2–5 have given some examples of the wide variety of experimental data which are being obtained from the three methods of data recovery in the Discoverer programme. It is important to emphasise, however, that the primary objective is the development of a versatile, reliable space vehicle. Undoubtedly the major problem confronting any designer of space vehicles or their equipment, at the present time, is the attainment of long operating lifetime under the special conditions of space. Equipments must continue to function for many weeks, or even years, without any adjustment or maintenance and in an unusual environment of almost a perfect vacuum. This high vacuum can give difficulties because of the steady evaporation of surface films or lubricating media. We have found significant effects of this type by

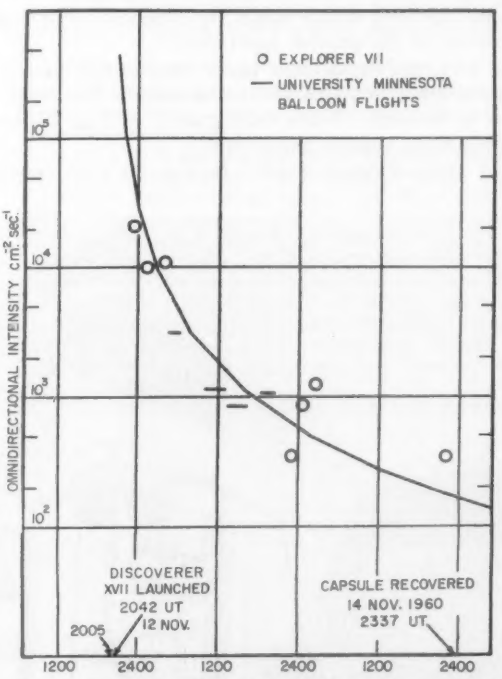

FIGURE 17. Radiation Flux Incident on the Discoverer XVII Satellite as a Function of Time Between Launching and Recovery of the Capsule.

studies of components in a small vacuum chamber at Lockheed Missiles and Space Division; this has been so useful during the early Discoverer flights that we are now building a much larger chamber, 18 ft. in diameter and 22 ft. long, able to provide a pressure as low as 10^{-8} mm of mercury (Fig. 18). This will be operating in September 1961.

Our attack on the problem of attaining long life is much more general than this, however. It seeks to identify the nature and probability of failure in each small component; for example, Fig. 19 shows the manner in which the failure rate of the typical condensers of an electronic chassis depends upon the working conditions of temperature and stress. Similar data are now available for a wide variety of the components used in space vehicles, and act as valuable guides to best working conditions.

When such data are combined, it is possible to define the general relation between the number of components which must operate in series and the lifetime of the assembly. The same type of relation can be obtained statistically, for example by collecting experience on the failure rate of airborne electronic equipment or of components of high-speed computers; collection of information of this type has been going on for a number of years on both sides of the Atlantic. The relation between lifetime and complexity shown in Fig. 20 is considerably more optimistic than experience on aircraft electronic equipment would indicate; it represents the order of performance which can be obtained by close attention to individual components such as is now given to high-speed computers or spacecraft equipment. Although controversial, it gives a rough idea of the lifetime on orbit which might be expected from space equipment of the present generation.

It is of vital importance to the success and economy of space flight that this lifetime should be increased as much as possible. From examination of Fig. 20, four possible ways suggest themselves:

(1) *Manned Space Flight.* In Fig. 20 a roughpoint

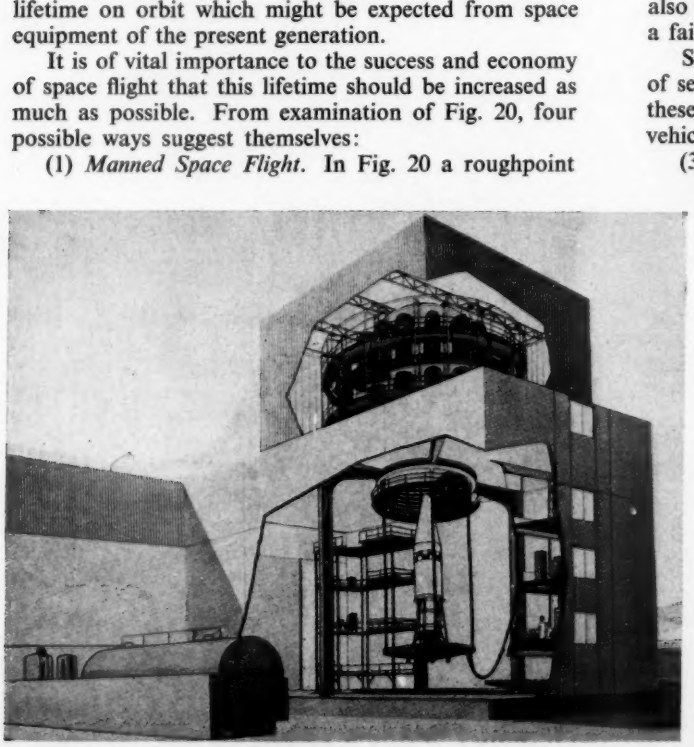

FIGURE 18. Lockheed Space Simulation Chamber.

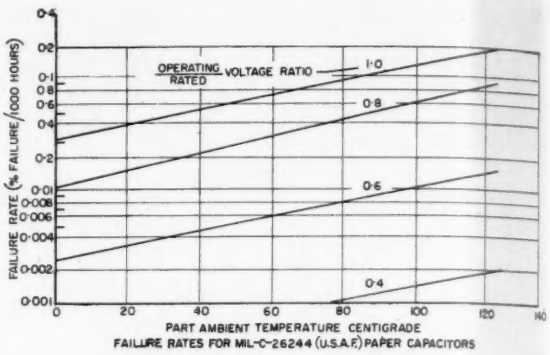

FIGURE 19. Lifetime of capacitors.

representing a human being has been inserted to emphasise his outstanding reliability. In spite of his extremely complex system (his brain alone has an estimated 10^{10} neurons), he has a life expectancy measured in scores of years. The recent achievement of the U.S.S.R. in placing a man in orbit, regarded in this light, is a long step towards the attainment of long life for complex operations on orbit.

(2) *Redundancy and Self-healing.* It becomes obvious, in studying the reasons for man's superiority in reliability, that these two features are adopted very widely in his method of operation. To a limited extent, they can also be incorporated in instrumented systems in space; and we are, in fact, building into the critical equipment area of the Agena vehicle and its payloads an appreciable amount of redundancy. The extent to which this can be done is limited by the total load-carrying capacity, and also by the need to have reliable methods of recognising a failure and switching over the redundant elements.

Some laboratory work is going on in the investigation of self-healing techniques for electronic equipment, but these have not yet been applied in practice to space vehicle equipment.

(3) *Simplicity.* An obvious step towards reliability is to reduce the number of elements which must operate to achieve a desired result. It is remarkable how much improvement in simplification can be obtained, while still performing the same essential function, by an insistence in simplicity in every phase of the design. In some of our Agena equipment, we have been able to reduce the number of components to perform a specific task by a factor of about 4, with corresponding improvement in the reliability. It is important to realise that many of the steps towards improved lifetime must be incorporated during the basic design of the equipment.

(4) *Development of More Reliable Components.* To many people who are familiar with the methods of quality control and inspection applied to aircraft equipment, this objective will raise the question of the adequacy of

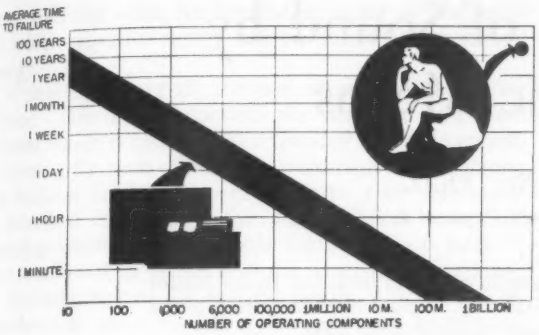

FIGURE 20. Dependence of lifetime on complexity.

such conventional quality control procedures. There is no doubt that all improvements in monitoring of manufacturing, established by the aircraft industry and the electronic industries, must be adopted and developed further for space flight. There is a need, in addition, for basic changes in concept which may produce significant gains in lifetime. To take an obvious example, recent replacement of the hot vacuum tube by the transistor for all but high-power, high-frequency application, appears to have given almost an order-of-magnitude improvement in lifetime, according to our statistics. There is now going on, in the United States, a major development effort in such areas.

I have deliberately stressed this question of long life on orbit, partly because of its major importance at present, but also because I believe that it is a basic problem in which the British research and development effort can contribute in a major way. "It may be that the standard American industrial methods of attaining reliability do not apply to the present satellite problem. The reliability of the Ford automobile has been attained by manufacturing them in millions, applying throughout the manufacture an empirical process of correcting the deficiences which showed up. This "automobile approach" has been applied in other areas; for example, the development of the reliable submarine cable tube involved the fabrication of many tens of thousands of prototypes. I suppose the classical story of Thomas Edison and the electric light filament is the earliest recorded example of this brute force approach to reliability. Actually the problem of attaining reliability after relatively few samples is quite new to American industry, and is more appropriate to some of the skills which have developed in England. We need the Rolls-Royce type of reliability in satellites, rather than the Ford car variety. I realise that I am being quite vague in this discussion, and, in fact, cannot make a specific suggestion; but I believe that the traditions of craftsmanship and of quality control over small quantity manufacture which are common in England could be the source of satellite equipment of greatly improved reliability. I also believe that some of your engineers and physicists in England could make valuable contributions to a more basic study of the factors influencing reliability, and could probably make more progress than our teams of quality control experts. I am not alone in this view; one of our foremost electronic scientists has commented that our reliability problems could best be solved by presenting the matter to a team of physicists."*

7. Acknowledgment

A project so wide in scope as the Agena-Discoverer programme is, of course, the product of the efforts of a large number of individuals, industrial organisations and Government laboratories. In the foregoing discussion I have mentioned only a few of the companies and laboratories which have contributed to some phase of the development. I would like to stress that, in giving this summary, I am acting as a reporter describing the co-operative efforts of a large number of individuals, craftsmen and engineers, who together made the Agena satellite possible.

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*Extract from a recent letter on the subject to Sir Solly Zuckerman.

The Generation of Sound by Aerodynamic Means

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SUMMARY: A summary is given of some of the more important experimental results relating to the noise radiated from a cold subsonic turbulent jet. These are then related to the predictions of Lighthill's general theory of aerodynamic noise.

1. Introduction

The subject of this paper is "Sound generated aerodynamically." It is perhaps as well to begin by making it quite clear just what is meant by aerodynamic sound, as distinct from sound generated by any other mechanism. Aerodynamic sound is defined as sound generated as a direct bi-product of a fluctuating air flow, without any essential part being played by vibrating solids.

You will all presumably know of at least two examples of aerodynamic sound. First of all there is the classical aeolian harp, consisting of a number of strings past which the air is allowed to blow. Provided that the Reynolds number is in the right range an anti-symmetrical vortex street is formed behind the cylinder, and a sound is heard, having the same frequency as that at which vortices are produced from the two sides of the string. It should be remarked that, although in practice the string will vibrate, the sound would still be generated if the string were rigid, so this sound comes within the definition above. Secondly, there is the modern (and notorious) example of the sound generated by a turbulent jet. Since turbulence is essentially random in character there is in this case a spectrum of frequencies rather than a discrete frequency, so that we should perhaps more properly call this aerodynamic noise.

In spite of the quite immense literature on acoustics, it was only quite recently—ten years ago roughly—that any serious attempt was made to estimate the intensity of the sound generated by an air flow, and this work, of course, was largely necessitated by adverse public reaction to the second of the two examples which I have just quoted, namely the noise generated by jet aircraft. Since this time, however, a considerable amount of work has been done and much progress made towards understanding the mechanisms of aerodynamic noise production, such understanding being then applied to the reduction of the noise. This work has been both theoretical (mainly by Lighthill[1]) and experimental (by a considerable number of workers, including Fitzpatrick and Lee[2], Lassiter and Hubbard[3] in America, and Gerrard[4] at Manchester, Lilley and Westley[5] at Cranfield, and Powell[6] at Southampton, in this country).

It is my purpose now to summarise some of the more important results obtained by these experimenters as to the nature of the noise generated by a turbulent jet. Going on from there, I shall discuss the general theory of aerodynamic noise and shall try to show how these experimental findings can be related to the predictions of the theory. We will consider, in order to make matters as free from complication as possible, only the case of a cold subsonic jet for which (not surprisingly, in view of the number of investigators) many of the experimental findings are well corroborated. These must all be adequately explained before a theory of aerodynamic noise can be regarded as satisfactory. They are as follows:—

(*i*) The acoustic power output of a turbulent jet varies as a high power of the jet velocity, usually near the eighth power. It is a consequence of this fact that it becomes too small for measurements to have been possible at Mach numbers much below about one-third.

(*ii*) Almost all the sound is radiated in directions making an acute angle with the jet, so much so that measurements behind the orifice are liable to error because the relatively low intensity there can be swamped by reflections of the sound of greater intensity which has been radiated forward.

(*iii*) The higher frequency sound is emitted mainly from the region near the orifice, where there is a mixing region with intense shear, and has a directional maximum at an angle of 45° to the jet axis, or slightly less.

(*iv*) The lower frequency sound has a directional maximum at a smaller angle to the jet axis. The angle decreases as either the frequency is reduced or the Mach number is increased. This lower frequency sound emanates mainly from the part of the jet of order 5 to 10 diameters downstream of the orifice.

2. Physical Discussion of Aerodynamic Noise Generation

Before dealing in detail with the mathematics of the theory, let us first look at the problem from a more physical point of view. I must stress that the theory evolved only through a combination of mathematical and physical ideas, and I am quite certain that it cannot be understood in any other way. Let us consider, then,

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three different ways (in descending order of efficiency) by which acoustic energy can be derived from kinetic energy.

Consider, first of all, the case of an acoustic pole or source. This may be conveniently visualised as a small balloon which is successively expanded and compressed, so causing the mass of fluid in a fixed region surrounding the balloon to fluctuate—in symbols, $\int \rho d\tau$ fluctuates. A practical example of this most efficient means of sound generation is the simple siren, in which puffs of air are allowed to escape into the surrounding medium.

We turn now to the acoustic dipole, which could be visualised as an oscillating sphere. It must be stressed here, however, that aerodynamic noise can be generated as by an acoustic dipole even when all solid bodies remain fixed. Thus, in flow past, say, a fixed rod, and taking a region which includes part of the boundary of the solid, the mass of fluid within the region does not change, but there are fluctuating forces exerted by the solid on the fluid, so that the momentum $\int \rho v_i d\tau$ of the fluid in the fixed region varies.

If, however, we consider a fluctuating fluid flow, away from solids, there is no change of either mass or momentum in a fixed region. But the momentum flux, which is the rate at which momentum in the x_i direction is being carried in the x_j direction, can vary. Expressed symbolically, $\int \rho v_i v_j d\tau$ varies. Intuitively, since the momentum ρv_i which is entering the fixed region must be reciprocated by momentum leaving the region across a different part of the boundary, one expects this mechanism to generate sound like two almost cancelling acoustic dipoles, that is like an acoustic quadrupole. This will be seen later to be true.

Let us now develop a formal mathematical approach to the problem, bearing in mind the physical ideas mentioned.

3. General Theory of Aerodynamic Noise

We begin by looking at the equations which describe the propagation of sound in a uniform medium at rest. With ρ = density, v_i = component of velocity in direction x_i, a_0 = velocity of sound in fluid at rest, these are

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho v_i) = 0, \quad . \quad . \quad (1)$$

$$\frac{\partial}{\partial t}(\rho v_i) + a_0^2 \frac{\partial \rho}{\partial x_i} = 0, \quad . \quad (2)$$

the first being the equation of continuity, and the second the approximate equation of momentum. Upon eliminating ρv_i, we find that

$$\frac{\partial^2 \rho}{\partial t^2} - a_0^2 \nabla^2 \rho = 0, \quad . \quad . \quad (3)$$

which is the classical equation for sound propagation.

Now the *exact* equation of momentum, which must be applied when the magnitudes of the velocity, density and pressure fluctuations in the flow are not infinitesimal, may be written as

$$\frac{\partial}{\partial t}(\rho v_i) + \frac{\partial}{\partial x_j}(\rho v_i v_j + p_{ij}) = 0, \quad . \quad (4)$$

where p_{ij} is the compressive stress tensor. Bearing in mind the approximate form (2) we may write (4) as

$$\frac{\partial}{\partial t}(\rho v_i) + a_0^2 \frac{\partial \rho}{\partial x_i} = -\frac{\partial}{\partial x_j}(T_{ij}), \quad . \quad (5)$$

where

$$T_{ij} = \rho v_i v_j + p_{ij} - a_0^2 \rho \delta_{ij}. \quad . \quad . \quad (6)$$

Upon eliminating ρv_i between (1) and (5) we obtain the result

$$\frac{\partial^2 \rho}{\partial t^2} - a_0^2 \nabla^2 \rho = \frac{\partial^2}{\partial x_i \partial x_j}(T_{ij}). \quad . \quad (7)$$

This is exactly the equation of sound propagation in a uniform medium at rest, acted upon by external fluctuating stresses, represented by the terms on the right-hand side. The fact that these forcing terms are exactly the sum of twice differentiated terms verifies that the sound is quadrupole in nature. We remark that, as Lighthill has indicated, the quadrupole strength density may often be approximated as $\rho_0 v_i v_j$.

Now extremely general solutions of (7) are well known. Consider the equation

$$\frac{\partial^2 \rho}{\partial t^2} - a_0^2 \nabla^2 \rho = Q'(\underline{x}, t) \quad . \quad . \quad (8)$$

where $Q'(\underline{x}, t)$ is the rate at which mass is being introduced at position $\underline{x}$ at time t—an acoustic source. Then the solution of (8) is

$$\rho - \rho_0 = \frac{1}{4\pi a_0^2} \int Q'\left(\underline{y}, t - \frac{|\underline{x}-\underline{y}|}{a_0}\right) \frac{d\tau(\underline{y})}{|\underline{x}-\underline{y}|}; \quad . \quad (9)$$

the integral is taken over all space. We may solve (7) by replacing Q' in (9) by $\partial^2 T_{ij}/\partial y_i \partial y_j$, and by twice applying the divergence theorem we obtain the result

$$\rho - \rho_0 = \frac{1}{4\pi a_0^2} \frac{\partial^2}{\partial x_i \partial x_j} \int T_{ij}\left(\underline{y}, t - \frac{|\underline{x}-\underline{y}|}{a_0}\right) \frac{d\tau(\underline{y})}{|\underline{x}-\underline{y}|} \quad (10)$$

A more enlightening method of obtaining this result, however, is to note that, since (7) is a linear equation, we may replace the quadrupole field by four source fields, and add together four solutions of the form (9), thus obtaining the second derivative of such a solution.

The solution (10) may often be simplified. At points far enough from the flow to be in the radiation field of each quadrupole, the differentiation may be applied to T_{ij} alone, so that

$$\rho - \rho_0 \simeq \frac{1}{4\pi a_0^2} \int \frac{(x_i - y_i)(x_j - y_j)}{|\underline{x}-\underline{y}|^3} \frac{1}{a_0^2} \frac{\partial^2}{\partial t^2} T_{ij}\left(\underline{y}, t - \frac{|\underline{x}-\underline{y}|}{a_0}\right) d\tau(\underline{y}). \quad . \quad (11)$$

For points at distances large compared with even the dimensions of the flow we may further approximate (11) as

$$\rho - \rho_0 \simeq \frac{x_i x_j}{4\pi a_0^4 x^3} \int \frac{\partial^2}{\partial t^2} T_{ij}\left(\underline{y}, t - \frac{|\underline{x}-\underline{y}|}{a_0}\right) d\tau(\underline{y}). \quad (12)$$

The presence of the second time derivative of T_{ij} in this equation is easy to understand physically.

Remembering that a quadrupole field is simply the limiting case of two dipole fields, we note that the total dipole strength is zero. The only reason why any sound is generated is that the values of the integrand are not simultaneous values—in other words, rays of sound from different dipoles which reach a distant point simultaneously were not usually emitted simultaneously. This factor is responsible for one time derivative in (12), the other arising because each dipole field is itself the limit of two source fields. Provided that fluctuations in $\partial^2 T_{ij}/\partial t^2$ are known, or can be estimated, then, assuming that T_{ij} is not itself almost a space derivative, non-trivial deductions from the integral in (12) may be made. This is not easy, however, as the following will show.

The intensity of the radiated sound is defined as

$$I = \frac{a_0^3}{\rho_0}\overline{(\rho-\rho_0)^2}, \qquad (13)$$

and may be formally deduced from (12) by writing it down twice (with different summation suffices), multiplying, combining the integrals into a double integral, and taking mean values. This yields

$$I(\underline{x}) = \left[\frac{x_i x_j x_k x_l}{16\pi^2 \rho_0 a_0^5 x^6}\right] \left[\int\int \overline{\frac{\partial^2}{\partial t^2} T_{ij}\left(\underline{y}, t - \frac{|\underline{x}-\underline{y}|}{a_0}\right) \frac{\partial^2}{\partial t^2} T_{kl}\left(\underline{z}, t - \frac{|\underline{x}-\underline{z}|}{a_0}\right)} d\tau(\underline{y})\, d\tau(\underline{z}).\right] \qquad (14)$$

It is the evaluation of the mean product which is the main problem. It will usually be permissible to neglect the differences in the retarded times, provided that eddy sizes are small compared with the acoustic wavelength. This point has been crucial in all calculations done to date.

It is useful at this stage to restore hope by examining how the sound generated by an unsteady fluid flow might depend upon the properties of the flow. We consider geometrically similar mechanisms of flow production. Then at points within the flow, the fluctuations in T_{ij} will be mainly proportional to $\rho_0 U_0^2$, with lesser dependence upon Reynolds number, Mach number and other parameters. Thus fluctuations in $\partial^2 T_{ij}/\partial t^2$ will be dominated by $\rho_0 U_0^2 n^2$, where n is a typical frequency of the fluctuating flow, which may be assumed to vary roughly like U_0/l, where l is a typical length in the flow, since nl/U_0 usually varies only slowly with Reynolds number and other parameters. We deduce, therefore, that the density variations in (12) are roughly

$$\rho - \rho_0 \propto \frac{1}{a_0^4 x} \rho_0 U_0^2 n^2 l^3 \simeq \rho_0 \left(\frac{U_0}{a_0}\right)^4 \frac{l}{x}. \qquad (15)$$

We note that, whereas density changes in the flow itself are proportional to M_0^2, radiated density changes depend on M_0^4. The additional factor arises solely through the quadrupole nature of the field. It follows from (15) that the intensity of the radiated sound is

$$I \propto \rho_0 U_0^8 (l/x)^2 a_0^{-5}, \qquad (16)$$

and the total acoustic power output, obtained by integrating the intensity over a large sphere, is

$$P_a \propto \rho_0 U_0^8 l^2 a_0^{-5}. \qquad (17)$$

It will be seen that this is in agreement with the first of the experimental findings listed earlier, namely, that the acoustic power output of a turbulent jet varies as a high power, near the eighth, of the jet velocity.

4. The Amplifying Effect of Shear

I have already remarked that it is a matter of experimental observation that a considerable amount of high frequency sound emanates from the heavily sheared mixing region immediately downstream of a jet exit. The explanation of this phenomenon lies in the fact that turbulence of a given intensity can generate more sound in the presence of a large mean shear.

We can see this semi-physically as follows. It is tempting to argue that $\rho v_i v_j$ can fluctuate most when fluctuations in v_i are multiplied by a large mean value $\bar{v}_j$. This, however, does not apply when $\bar{v}_j$ is uniform, since the first time derivative of $\rho v_i \bar{v}_j$ is then exactly a space derivative, as may be seen from (4), so that its integral over all space is zero and the quadrupole field degenerates to an octupole field. It follows, therefore, subtracting out the uniform part of $\bar{v}_j$, that the largest fluctuations in $\rho v_i v_j$ occur when there are wide changes in $\bar{v}_j$ over the region in which values of ρv_i are correlated, that is when there is a large mean-velocity gradient.

Lighthill[1] has put this argument in a precise mathematical form by using the exact equations of motion to show that

$$\frac{\partial}{\partial t}(\rho v_i v_j) = p_{ik}\frac{\partial v_j}{\partial x_k} + p_{jk}\frac{\partial v_i}{\partial x_k} - \frac{\partial}{\partial x_k}(\rho v_i v_j v_k + p_{ik} v_j + p_{jk} v_i). \qquad (18)$$

We note that the last of these terms is a space derivative, representing an octupole field; the importance of velocity gradient in the residual quadrupole field is apparent. Moreover, the mean viscous stresses are known to be small compared with the turbulent shearing stresses, which in turn are comparable with the pressure fluctuations, and the viscous stress fluctuations are usually small compared with the pressure fluctuations in fully developed turbulence. Accordingly the dominant term in (18) is simply

$$p\left(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i}\right) = p e_{ij}, \qquad (19)$$

that is, the product of pressure and rate of strain, and we further approximate this as

$$\frac{\partial}{\partial t}(T_{ij}) \simeq \overline{p e_{ij}}, \qquad (20)$$

since fluctuations in e_{ij} are presumably small compared with $\bar{e}_{ij}$ itself when this is large enough.

Substituting in (14), with differences in retarded times neglected, we find that the sound generated by unit volume of turbulence at the origin is

$$I(\underline{x}) = \frac{x_i x_j x_k x_l}{16\pi^2 \rho_0 a_0^2 x^6} \int \bar{e}_{ij}(\underline{0})\, \bar{e}_{kl}(\underline{z})\, \overline{\frac{\partial p}{\partial t}(\underline{0}, t)\, \frac{\partial p}{\partial t}(\underline{z}, t)}\, d\tau(\underline{z}). \qquad (21)$$

Lilley[7] has shown how the $\partial p/\partial t$ covariance in this equation may be evaluated approximately, making use of the presence of a large mean shear to effect considerable approximations in his analysis. When the dominant rate of strain is e_{12} (corresponding to a velocity gradient $\partial v_2/\partial x_1$) his result becomes

$$I(\underline{x}) \simeq 0{\cdot}05 \frac{x_1^2 x_2^2}{\rho_0 a_0^5 x^6} L_{11}^5 \overline{e_{12}}^6 \overline{\rho^2}\,\overline{v^2}\alpha \quad . \qquad (22)$$

for the intensity, and

$$P_s \simeq \frac{0{\cdot}08}{\rho_0 a_0^5} L_{11}^5 \overline{e_{12}}^6 \overline{\rho^2}\,\overline{v^2}\alpha \quad . \qquad (23)$$

for the total acoustic power output, where L_{11} is the longitudinal integral velocity scale of the turbulence and α is an anisotropy factor, probably of order 0·4.

We note, in passing, that the intensity distribution (22) is dependent upon the sixth power of the mean shear and has a maximum at an angle of 45° to the jet axis. This partly explains experimental finding (*iii*); a fuller explanation will become apparent later.

5. Noise Generated by Isotropic Turbulence

Proudman[8] has calculated the noise generated by unit volume of decaying isotropic turbulence, using a combination of Lighthill's theory and techniques from the statistical theory of isotropic turbulence. He shows first that the intensity is given by

$$I(\underline{x}) = \frac{\rho_0}{16\pi^2 a_0^2 x} \int \overline{\frac{\partial^2}{\partial t^2}[v_x^2(\underline{0}, t)]\frac{\partial^2}{\partial t^2}[v_x^2(\underline{z}, t)]}\, d\tau(\underline{z}), \qquad (24)$$

where v_x is the velocity component in the direction of emission. By then using the well-founded approximation that the fourth-order covariance may be replaced by the same combination of second-order covariances that it would equal if v_x and its first two derivatives at $\underline{0}$ and $\underline{z}$ had a normal joint-probability distribution, he was able to show that the intensity equalled

$$I(\underline{x}) \simeq \frac{\rho_0}{4\pi x^2} 38 \frac{(\overline{v_1^2})^{5/2}}{a_0^5} \varepsilon, \qquad (25)$$

where ε is the mean rate of dissipation of energy per unit mass, and the acoustic power output

$$P_s \simeq 38 \rho_0 \varepsilon \frac{(\overline{v_1^2})^{5/2}}{a_0^2} \quad . \quad . \qquad (26)$$

6. The Influence of Convection

When the quadrupoles are moving at non-negligible speeds the critical approximation, that the retarded times may be ignored in calculating the intensity, breaks down. If, however, the turbulence is analysed in a frame of reference which moves at such a speed that distortions of the quadrupoles are minimised, then the importance of the differences in retarded times is reduced. Put another way, we analyse the turbulence in a frame of reference for which the time scale of the fluctuations of $\partial^2 T_{ij}/\partial t^2$ is greatest.

Time will not permit me to go into details, for which I must refer you to Lighthill's two papers. He shows that when the co-ordinate system moves with uniform velocity $a_0 M_c$, so that T_{ij} refers to momentum flux across surfaces moving uniformly through the fluid, the formula (14) for intensity (with retarded times set equal) must be multiplied by

$$(1 - M_c \cos\theta)^{-6} \quad . \quad . \qquad (27)$$

outside the integral, θ being the angle between the directions of motion and emission. It follows that, for prescribed fluctuations in $\partial^2 T_{ij}/\partial t^2$, fluctuations across moving surfaces send increased sound in a forwards direction and decreased sound in a backwards direction, which explains the experimental finding (*ii*). The physical reasons for this effect are two-fold: —

(*i*) Considering a single quadrupole as four sources filling an infinitesimal volume, the positions of origin of the rays of sound which reach a distant point simultaneously fill a greater volume for forward emission, since the foremost source has moved on before it emits its sound.

(*ii*) The time interval between emission is greater for sound emitted forwards, so that cancelling between the source fields is mitigated.

The effects of convection may easily be sketched into the earlier results. Thus, for a heavily sheared layer, the formula (22) for the intensity becomes

$$I(\underline{x}) \simeq 0{\cdot}05 \frac{x_1^2 x_2^2}{\rho_0 a_0^5 x^8 (1 - M_c \cos\theta)^6} L_{11}^5 \overline{e_{12}}^6 \overline{\rho^2}\,\overline{v^2}\alpha,$$

$$\simeq \frac{0{\cdot}05 \sin^2\theta \cos^2\theta}{\rho_0 a_0^5 x^2 (1 - M_c \cos\theta)^6} L_{11}^5 \overline{e_{12}}^6 \overline{\rho^2}\,\overline{v^2}\alpha, \qquad (28)$$

and the acoustic power output

$$P_s \simeq 0{\cdot}08 \frac{1 + 5M_c^2}{(1 - M_c^2)^4} \frac{L_{11}^5 \overline{e_{12}}^6 \overline{\rho^2}\,\overline{v^2}\alpha}{\rho_0 a_0^5} \quad . \qquad (29)$$

Similarly, the intensity due to unit volume of isotropic turbulence convected at an eddy-convection velocity $a_0 M_c$ becomes

$$I(\underline{x}) \simeq \frac{\rho_0}{4\pi x^2 (1 - M_c \cos\theta)^6} 38 \frac{(\overline{v_1^2})^{5/2}}{a_0^5} \varepsilon, \qquad (30)$$

with an associated acoustic power output

$$P_s \simeq 38 \frac{1 + 2M_c^2 + \frac{1}{5}M_c^4}{(1 - M_c^2)^5} \rho_0 \varepsilon \frac{(\overline{v_1^2})^{5/2}}{a_0^5} \quad . \qquad (31)$$

7. Application to the Noise of a Turbulent Jet

The way in which these various elements may be combined to provide answers to the questions raised earlier is almost obvious.

Taking, first of all, the question of the high-frequency noise from the mixing-region, we note from (22) and (28) that the "shear-noise" (due to the interaction between the turbulence and the large mean shear) has an intensity maximum at 45° in the absence of convection, this angle decreasing as the convection Mach number increases. In a heavily sheared mixing region the relevant value of $a_0 M_c$ will be of order 40 per cent of the mean velocity of the jet at the

orifice. Accordingly, when the Mach number is about 0·3 the convection Mach number is about $M_c \sim 0{\cdot}12$, and the maximum intensity given by (28) occurs when $\theta = 41°$.

A second reason why the maximum intensity occurs at an angle slightly less than 45° (rather than greater) is that in addition to the shear-noise there is also a contribution due to the interaction of the turbulence with itself. Lilley has indicated that this "self-noise" is much smaller, as one would expect. This contribution has less strong directional properties in the absence of convection, the convection tending to produce a maximum of intensity in the direction of the jet axis. The secondary high-frequency noise, when added to the more important shear-noise, would tend to reduce the angle of the maximum intensity slightly.

Turning now to the low frequency noise, coming mainly from the region 4 to 6 diameters downstream of the orifice, this again is of both types, shear-noise and self-noise. As the shear is much less intense in this region, the noise generated thereby is relatively reduced. In fact, Lilley suggests that the power output of the two types will be of similar order of magnitude. Accordingly the position of the peak will be brought (by the self-noise) to a lower angle much more effectively. This explains why the low frequency noise has a peak intensity in a direction making much less than 45° with the jet axis. Further, the effect of increasing the Mach number is to increase the sound radiated in a forward direction, reducing the angle still further. Similarly, as the frequency decreases the efficiency of the cancelling out of the four source fields is less for forward emission, causing a similar reduction in the angle of the peak intensity.

Finally, we turn to the variation of acoustic power output with jet velocity. At first sight it would seem that the agreement between theory and experiment is very good, since the prediction of equation (17), that the acoustic power output varies as roughly the eighth power of the jet velocity, appears to be borne out by experiment. It must be remembered, however, that (17) takes no account of the quadrupole convection effect, which has been shown to be an essential part of the theory, and should cause the dependence on jet velocity to be increased to a higher power than the eighth. A more careful analysis of the experiments indicates that some other dependence on velocity appears to be present, which is not accounted for in the theory, bringing the dependence back to eighth power. Thus, in a direction $\theta = 90°$, where the convection effect is absent, exponents ranging from 5·5 to 7·0 are obtained in a large number of experiments, indicating that the basic acoustic power output is increasing less rapidly than U_0^8, and that the U_0^8 dependence is more closely achieved only when the quadrupole convection effect is accounted for.

A partial explanation of this phenomenon is that the intensity of the turbulence itself may decrease at high subsonic Mach numbers, and there appears to be a certain amount of experimental evidence to support this idea. For example, it is known that supersonic jets mix more slowly with the outer air than subsonic jets, suggesting that they have less intense turbulence in the mixing region. What this really amounts to is that sufficient sound energy is radiated from the turbulence that the intensity of the turbulence itself is impaired.

This, however, is only a partial explanation. It should be noted, further, that this last point really comes outside the scope of the theory anyhow, since the theory assumes that there is no significant back-reaction of the radiated sound upon the flow. Even so, it will be seen that the effect can be sketched in afterwards, at least in a qualitative way.

In conclusion, I must remark that shortage of time has meant that I can give you only the bare outlines of the comparison between theory and experiment. A much more detailed analysis, for both subsonic and supersonic jets, has been made by Lilley[7], including comparisons of predicted and measured spectra. No doubt much more could be done, if we knew more about the details of the turbulent structure of the jet, and various workers, notably at Southampton, are studying this problem. We may say, however, that it has been possible by means of Lighthill's theory to explain adequately in a general way all the basic features of noise generation by aerodynamic means.

Acknowledgment

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A Method of Estimating the Permissible Fatigue Life of the Wing Structure of A Transport Aircraft

BY

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1. Introduction

For types of structure where safety standards cannot be preserved by reliance on inspection, a permissible "safe life" has to be determined by relating the loads experienced by the aircraft in service to the fatigue performance of the structure, with due allowance for scatter in fatigue strength and in the frequency with which loads are encountered. This paper gives a working method for estimating the "safe life"—at which the risk of fatigue failure is negligible—of the wing structure of a transport aircraft, where the flight loads giving rise to fatigue are overwhelmingly due to atmospheric turbulence but where allowance has also to be made for "ground-to-air" loads.

The problem is outlined first in general terms and the assumptions made are discussed. A method of estimating the permissible fatigue life is then developed, following broadly on the lines suggested by Taylor[1]. A family of damage curves is presented, from which the permissible life of the wing can readily be determined. Numerical examples are given to illustrate the use of the curves.

In practice the estimation of fatigue life of a particular aircraft type is usually done in three stages:—

(*i*) A preliminary assessment based on the estimated fatigue strength of components which are likely to be critical.

(*ii*) A second assessment based on the results of laboratory fatigue tests on specimens representing critical components. (This may be considered as design development.)

(*iii*) Final clearance based on fatigue tests on the complete structure.

The third stage is very necessary as it is difficult to predict the behaviour of a complete structure from the theoretical stress distribution and from laboratory tests on structural details. Experience has shown that in many cases detail tests seriously under-estimate the life of the complete structure.

The method outlined in this paper can be applied equally well to any of the above stages and in the examples given it has not been thought necessary to state whether the test results apply to the results of tests on laboratory specimens or on the full-scale structure.

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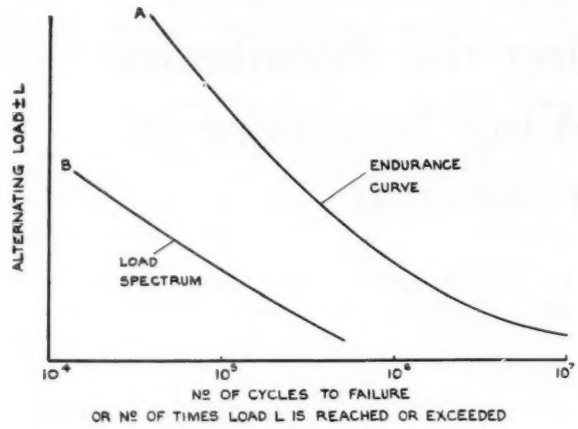
NOTATION

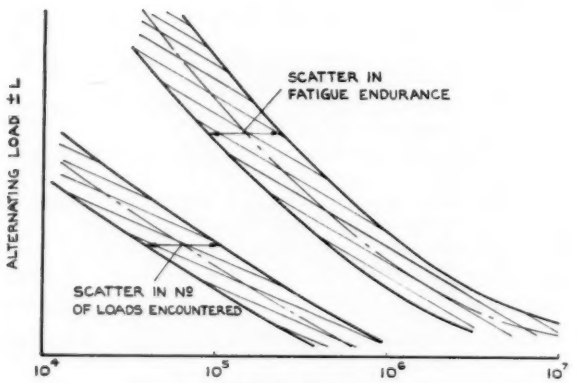
D	fatigue damage or proportion of life expended
D_0	fatigue damage per 10^6 miles of flight for standard gust spectrum, and "safe life endurance curve"
D_F	factored fatigue damage per flight due to gust loading
D_T	factored fatigue damage per hour of typical flight due to gust loading
D_G	factored fatigue damage per flight due to ground-to-air loading
E	number of load cycles equal to or exceeding L
E_0	number of cycles of alternating stress f produced by standard gust spectrum
f	alternating stress on net cross sectional area
f_{10}	alternating stress produced by 10 ft./sec. gust
f_m	mean stress on net cross sectional area
f_∞	alternating stress which just causes no fatigue damage
f_∞'	value of f_∞ for derived endurance curve for actual component at $f_m = 13{,}000$ lb./in.^{2}
f_0	alternating stress for "average joint curve"
f_0'	alternating stress on average joint curve to give failure in N' cycles
F	number of gusts
h	altitude correction factor
K_n	scatter factor on fatigue strength
L	alternating load
n	number of load cycles applied
N	number of load cycles to cause failure
N_0	number of load cycles to cause failure on average joint curve
N'	number of load cycles to cause failure corrected to $f_m = 13{,}000$ lb./in.^{2}
N_G	number of load cycles to cause failure under ground-to-air loading
p	proportion of total flight length
$r = f/f_0'$	
T	duration of flight in hours
v	gust velocity
V	average true air speed of flight in m.p.h.

2. Outline of the Problem

The damaging effect of a particular set of loads is calculated from a knowledge of the fatigue performance of the structure associated with a load spectrum representing the number of times loads of particular magnitudes are encountered. The fatigue performance is expressed as the familiar endurance curve (Curve A,



(*a*) AVERAGE CURVES



(*b*) SCATTER BANDS

FIGURE 1. Diagrammatic representation of endurance curve and load spectrum.

Fig. 1(*a*)) which shows how many cycles, N, of an alternating load $\pm L$ must be applied to the structure to cause failure. The load spectrum (Curve B, Fig. 1(*a*)) shows how many times a load cycle of $\pm L$ is reached or exceeded in a given time. In order to assess the fatigue damage caused by these loads some form of cumulative fatigue damage relationship must be assumed.

The curves shown in Fig. 1(*a*) represent average values and could only be used directly if there were no scatter in fatigue performance or in load frequencies between one aircraft and another in the same fleet. In fact, both fatigue performance and load spectrum should be represented by bands (*see* Fig. 1(*b*)). The problem of determining the safe life becomes in essence the determination of the life appropriate to a structure whose fatigue strength is less than average associated with loads which occur with a higher intensity than the average for the particular route. In practice the situation is further complicated by the small number of fatigue test results that are usually available.

In brief, the problem is to estimate the permissible life of the weakest aircraft when only a limited number of test results are available. In this assessment allowances have to be made for the actual number of test results, the probable scatter in fatigue performance of the structure and the probable variation in the frequency with which loads occur during the normal operation of the aircraft.

The assumptions made in the proposed method of fatigue life estimation are discussed under Fatigue Loads, Fatigue Performance and Fatigue Damage.

3. Fatigue Loads

3.1. GUSTS

For civil transport aircraft the most significant fatigue loads are those arising from atmospheric turbulence and the frequency of occurrence of gusts of different magnitudes has been determined from counting accelerometers installed in civil aircraft operating over a number of different routes. For fatigue life prediction the following simplifying assumptions are made:—

(*i*) In turbulence each up gust is immediately followed by a down gust of equal magnitude.

(*ii*) In a given distance flown the actual number of ranges of gust velocity encountered (*i.e.* between $+v$ and $-v$ ft./sec.) is 0·85 times the number indicated by the counts recorded on a counting accelerometer. This factor has been deduced by comparison with continuous trace records of acceleration[9, 10].

(*iii*) The relative frequency of occurrence of gusts of different magnitudes is independent of altitude[3]. The effect of altitude can therefore be allowed for by applying a single correction factor.

(*iv*) The increment of lift due to a gust acts on the wing alone and reaches its peak value before there is any change in tail load.

(*v*) Dynamic overswing of wing stress is assumed to be of the same order as the dynamic overshoot of acceleration as measured by the counting accelerometers from which the basic gust data were derived.

(*vi*) A mass-parameter gust alleviating factor[3] is used in converting gust velocities to loads on the structure.

The gust data presented in this paper have been derived from measured accelerations using assumptions (*iv*) and (*vi*). The same assumptions must therefore be made in converting gusts to loads in the aircraft structure.

3.2. GROUND TO AIR LOADS

In many cases a significant fatigue load cycle arises from the variation of wing bending moment due to transfer of the weight of the aircraft from the undercarriage when on the ground, to lift on the wing when in flight. This load cycle occurs once per flight and is particularly significant when there are fuel tanks outboard of the undercarriage.

The load cycle is assumed to be from the maximum down load at take-off with full fuel to the maximum up load occurring in level flight. For aircraft operating off runways an average value of the maximum normal acceleration during taxying out to the take-off point is

of the order of $1{\cdot}2g$; for operations from grass fields a value of $1{\cdot}5g$ is suggested.

3.3. SCATTER IN LOAD FREQUENCIES

If loads are measured on each individual aircraft no factor is required to allow for scatter in load frequencies, since the permissible life will be based on the measured loads. In all other cases it is assumed that any aircraft in a fleet encounters gust loads which occur with 1·5 times the frequency predicted from average gust data for the route. In the case of ground-to-air loads, their frequency will usually be known more accurately than the flight loads and a factor of 1·2 is assumed.

4. Fatigue Performance

4.1. ENDURANCE CURVE

Having tested a number of specimens at a particular alternating load, the endurance at any other alternating load can be predicted reasonably well by assuming a general shape of curve passing through the mean of the test results. To minimise errors the test loading should be close to the most damaging load level. This is discussed further in Appendix I.

4.2. EFFECT OF VARIATION IN MEAN LOAD

To allow for variations in $1g$ level flight load, which is the mean load of the fatigue cycle due to gusts, it is assumed that for a particular alternating load the endurance is inversely proportional to the mean load[5].

4.3. SCATTER IN FATIGUE STRENGTH

The permissible life is based on a component which has a fatigue strength of three standard deviations less than the mean fatigue strength of the component. (Fatigue strength is defined as the alternating stress that produces failure in a given number of cycles at a particular mean stress.) On the assumption that the frequency distribution of fatigue strength approximates to a Gaussian distribution this represents a small risk of failure, which for practical purposes may be considered to be negligible. This is thought to be a more rational way of allowing for scatter in fatigue performance than factoring endurances.

The results of laboratory tests on components and structures indicate that the coefficient of variation of fatigue strength is of the order of 0·1 and this value is assumed for the prediction of the safe life. It may be noted that comparable values for static strength[3] are between 0·02 and 0·06.

5. Fatigue Damage

The method of fatigue life assessment is based on the Palmgren-Miner cumulative damage hypothesis. This states that the proportion of fatigue life used up when n cycles of a particular alternating load are applied may be expressed by n/N, where N = number of cycles of that load to cause failure. If a number of load levels are applied the life used is given by

$$\frac{n_1}{N_1}+\frac{n_2}{N_2}+\frac{n_3}{N_3}+\ldots\ldots \quad \text{or} \quad \sum\frac{n}{N},$$

and failure occurs when $\sum\frac{n}{N}=1$.

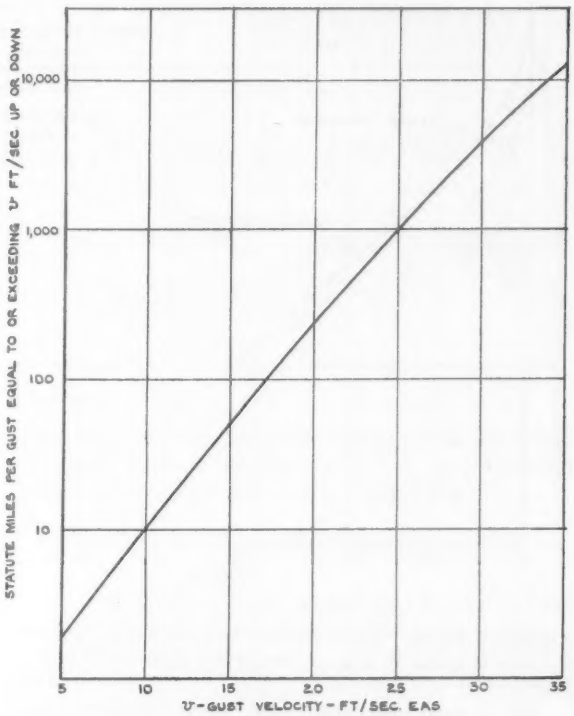


FIGURE 2. Standard gust spectrum (average gust frequencies at 5,000 ft.)

It is found in practice that most of the fatigue damage is done over a fairly narrow range of gust velocities (about 5 ft./sec. to 20 ft./sec.), and it seems reasonable to expect that Miner's rule would not be seriously in error over this range. Recent work on random loading and programme loading suggests that Miner's rule may be slightly conservative when applied to a wing structure.

6. Gust Load Spectrum

The relative frequencies of occurrence of gusts of different magnitudes at any altitude may be represented by the following relationship[2]:—

$$F=27{\cdot}8\exp.\left(-\frac{v}{2{\cdot}906}\right)+0{\cdot}878\exp.\left(-\frac{v}{4{\cdot}803}\right) \quad . \quad . \quad . \quad (1)$$

where F = number of gusts equal to or exceeding v ft./sec. for each gust of 10 ft./sec. or greater.

The average frequency with which gusts of a particular magnitude are equalled or exceeded varies with altitude and to some extent with geographical and climatic conditions. Fig. 2 shows the average frequency of occurrence of gusts at an altitude of 5,000 ft., at which altitude a 10 ft./sec. up or down gust is equalled or exceeded on average every 10 miles. On the assumption that each up gust is followed by a down gust of equal magnitude, Fig. 2 represents a $\pm$10 ft./sec. gust cycle every 20 miles. It is convenient for analysis to refer to Fig. 2 as a standard gust spectrum and to allow for variation with altitude by applying a single altitude

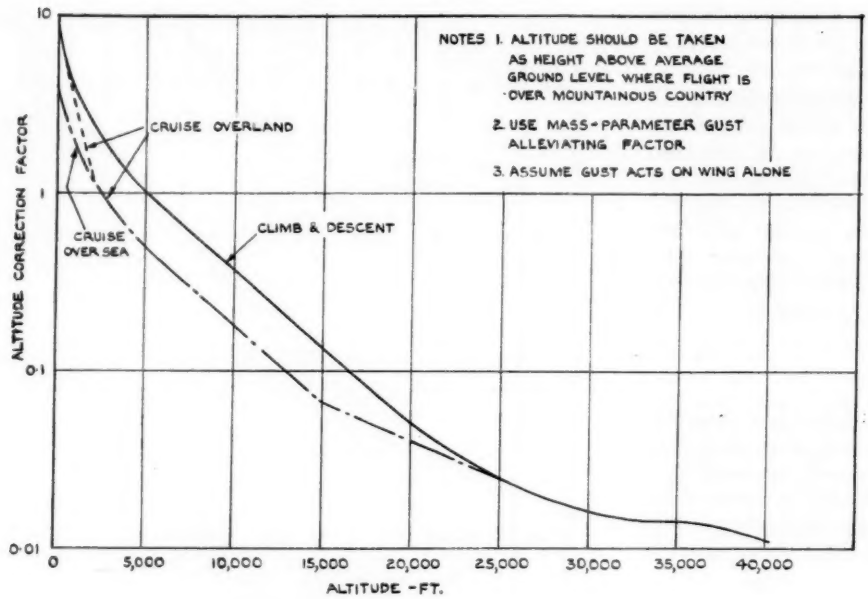


FIGURE 3. Altitude correction factors.

correction factor. The variation of gust frequency with altitude is given in Fig. 3, which is based on Fig. 2 of Ref. 2.

For a particular weight and speed, the stress in a wing spar boom is directly proportional to the gust velocity. The number of alternating stress cycles per 10^6 statute miles of flight, derived from equation (1), may then be expressed for the standard gust spectrum as follows:—

$$E_0 = 1{,}390{,}000 \exp.\left(-\frac{f}{0{\cdot}2906 f_{10}}\right) + 43{,}900 \exp.\left(-\frac{f}{0{\cdot}4803 f_{10}}\right) \quad . \quad . \quad (2)$$

where E_0 is number of cycles of alternating stress f per 10^6 miles of typical flight at the height at which a 10 ft./sec. gust up or down is reached or exceeded once every 10 miles (*i.e.* a gust cycle every 20 miles).

f_{10} is stress corresponding to a 10 ft./sec. E.A.S. gust at the appropriate weight and speed.

7. Derivation of Endurance Curve for a Particular Component

In general it is not possible to determine a complete endurance curve for the particular component under consideration. It is sufficiently accurate, however, to determine the endurance at one particular load level by test and to assume from experience a general shape for the endurance curve to pass through this point, provided that the test loading is not too far removed from the most damaging load level. The significance of the level of the test loading is discussed in Appendix I, and it is there suggested that for light alloy structures the alternating stress applied in the test should be that associated with a 10 ft./sec. gust or 3,500 lb./in.^{2}, whichever is the greater.

Over a limited range of endurances the shape of a typical endurance curve for a wing component may be expressed in the following form

$$f = f_\infty \left(1 + \frac{C}{\sqrt{N}}\right) \quad . \quad . \quad . \quad (3)$$

or alternatively

$$N = C^2 \left(\frac{f_\infty}{f - f_\infty}\right)^2 \quad . \quad . \quad . \quad (4)$$

where f is alternating stress on net area at section of failure

f_∞ is alternating stress which just causes no fatigue damage

N is number of cycles to failure

C is a "shape" constant.

Heywood[4] has suggested that for typical wing joints in aluminium alloy, tested at a mean stress of about 13,000 lb./in.^{2}, f_∞ and C have the following values:—

$$f_\infty = 1{,}500 \text{ lb./in.}^2 \quad C = 1{,}000.$$

Equation (3) then becomes

$$f_0 = 1{,}500\left(1 + \frac{1{,}000}{\sqrt{N_0}}\right) \quad . \quad . \quad . \quad (5)$$

This will be termed the "average joint curve."

An average endurance curve for a particular component may now be constructed as follows:—

Let N_T = geometric mean endurance of a number of fatigue tests at an alternating stress f_T and a mean stress f_m

N_T' = corresponding endurance at a mean stress of 13,000 lb./in.^{2}

f_0' = alternating stress on average joint curve to give failure in N_T' cycles.

It is assumed that endurance is inversely proportional to mean stress[3]. Hence $N_T' = N_T f_m / 13{,}000$.

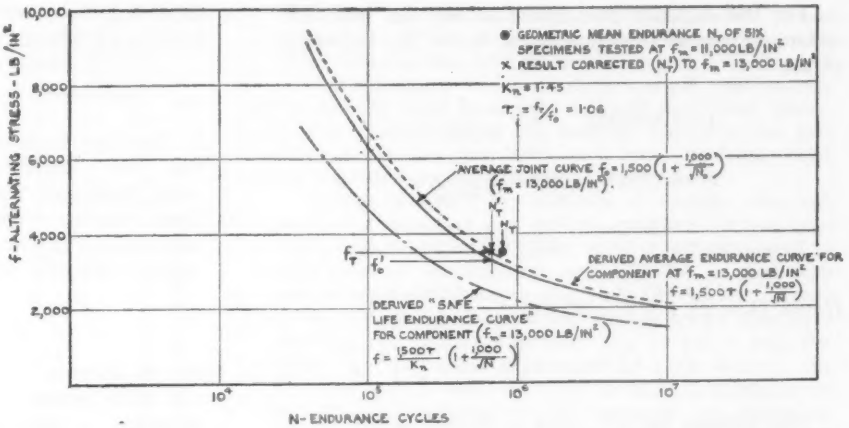

f - ALTERNATING STRESS - LB/IN²
10,000
8,000
6,000
4,000
2,000
10⁴
10⁵
10⁶
10⁷
N - ENDURANCE CYCLES
● GEOMETRIC MEAN ENDURANCE N_T OF SIX SPECIMENS TESTED AT f_m = 11,000 LB/IN²
× RESULT CORRECTED (N_T') TO f_m = 13,000 LB/IN²
K_n = 1·45
T = f_T/f_0' = 1·06
AVERAGE JOINT CURVE f_0' = 1,500 (1 + 1,000/√N)
(f_m = 13,000 LB/IN²).
N_T'
N_T
f_T
f_0'
DERIVED AVERAGE ENDURANCE CURVE FOR COMPONENT AT f_m = 13,000 LB/IN²
f = 1,500T (1 + 1,000/√N)
DERIVED "SAFE LIFE ENDURANCE CURVE" FOR COMPONENT (f_m = 13,000 LB/IN²)
f = (1500T/K_n) (1 + 1,000/√N)

FIGURE 4. Endurance curves derived from tests at a single load level.

If C is assumed constant for a particular mean stress then $\frac{f_\infty'}{1,500} = \frac{f_T}{f_0'} = r$, say, for a mean stress of 13,000 lb./in.², and the average endurance curve for the component corrected to a mean stress of 13,000 lb./in.² is given by

$$f = 1,500r\left\{1 + \frac{1,000}{\sqrt{N}}\right\} \quad . \quad . \quad . \quad (6)$$

The construction of this curve is illustrated in Fig. 4.

8. Prediction of "Safe" Fatigue Strength

The "safe" life is based on a component whose fatigue strength is three standard deviations below the mean fatigue strength. The endurance curve for such a component corrected to a mean stress of 13,000 lb./in.² is given by:—

$$f = \frac{1}{K_n} \times 1,500r\left\{1 + \frac{1,000}{\sqrt{N}}\right\} \quad . \quad . \quad (7)$$

where K_n = factor to give three standard deviations below the true mean fatigue strength.

This curve will be referred to as the "safe life endurance curve" and is shown as the lowest curve in Fig. 4. The value of K_n depends on the number of specimens tested[6] and is given in Table I. In practice one would rarely test more than six specimens of a major component and in fact the table shows that there is little advantage in doing so. It is not possible to express these factors directly in terms of equivalent factors or endurance, as the latter would depend on the stress levels and the integrated damage over the whole spectrum. In most cases, however, a K_n of 1·43 would be equivalent to a life factor of between 3 and 4.

TABLE I

VALUES OF SCATTER FACTOR K_n TO GIVE FATIGUE STRENGTH THREE STANDARD DEVIATIONS BELOW MEAN. COEFFICIENT OF VARIATION = 0·10.

No. of specimens tested	*Factor on alternating load or stress*
1	1·56
2	1·50
3	1·48
4	1·46
6	1·45
10	1·445
20	1·44
100	1·43
1000	1·43

9. Factored Fatigue Damage due to Gust Loads

The gust load spectrum is expressed in terms of the number of times a given gust is reached or exceeded.

Chilver[7] has shown that the simple cumulative damage concept can then conveniently be expressed in the integral form:—

$$D = -\int_0^\infty \frac{dE}{N}$$

$$D = -\int_0^\infty \frac{1}{N}\frac{dE}{dL}\,dL \quad . \quad (8)$$

where D is proportion of fatigue life expended
E is number of load cycles equal to or exceeding $\pm L$
N is number of applications of load cycle $\pm L$ to cause failure.

Equation (2) may be written

$$E_0 = A\exp.(-af) + B\exp.(-bf) \quad . \quad (9)$$

and equation (7) may be written in the form of equation (4) as

$$N = C^2\left\{\frac{f_\infty}{f - f_\infty}\right\}^2$$

where $C^2 = 10^6$

and $f_\infty = \frac{1,500r}{K_n}$

Substituting (9) and (4) into (8), the total damage per 10^6 miles becomes

$$D_0 = -\int_{f_\infty}^\infty \frac{1}{N} \cdot \frac{dE}{df} \cdot df$$

$$= \int_{f_\infty}^\infty \frac{1}{C^2}\left\{\frac{f - f_\infty}{f_\infty}\right\}^2 \{aA\exp.(-af) + bB\exp.(-bf)\}\,df$$

$$= \frac{1}{C^2 f_\infty^2}\left\{\frac{2A}{a^2}\exp.(-af_\infty) + \frac{2B}{b^2}\exp.(-bf_\infty)\right\}. \quad (10)$$

For the standard gust spectrum and the "safe life endurance curve" the constants have the following values

$$A=1{,}390{,}000 \qquad a=\frac{1}{0{\cdot}2906f_{10}}$$

$$B=43{,}900 \qquad b=\frac{1}{0{\cdot}4803f_{10}}$$

$$f_\infty=\frac{1{,}500r}{K_n} \qquad C^2=10^6.$$

$$\text{Hence } D_0=\frac{f_{10}^2}{10^6}\left(\frac{K_n}{r}\right)^2\left\{105\exp.\left(-\frac{5{,}160}{f_{10}}\frac{r}{K_n}\right)+9{\cdot}01\exp.\left(-\frac{3{,}120}{f_{10}}\frac{r}{K_n}\right)\right\} \quad . \quad (11)$$

The damage per 10^6 miles is plotted against f_{10} in Fig. 5 for various values of r/K_n. These curves are based on a gust frequency of a ± 10 ft./sec. gust cycle being reached or exceeded once every 20 miles. The damage rates so calculated are therefore appropriate to a particular altitude of 5,000 ft. and appropriate altitude correction factors must be applied to calculate the damage at any other altitude. f_{10} varies with weight, speed and fuel disposition and has to be determined for various stages of the flight.

In order to allow for variation in mean load during flight it is sufficiently accurate to assume that all endurances are inversely proportional to mean stress, hence the damage rate at any stage of the flight is given by $D_0 f_m/13{,}000$. Making the assumptions of Sections 3.3 and 3.1, allowance has to be made for $1{\cdot}5\times 0{\cdot}85$ (*i.e.* 1·275) times the damage indicated by the curves. For convenience this is called "factored damage" and for 10^6 miles of flying is given by:—

$$D=1{\cdot}5\times 0{\cdot}85\sum\left(ph\frac{f_m}{13{,}000}D_0\right)$$

$$=1{\cdot}275\sum\left(ph\frac{f_m}{13{,}000}D_0\right) \quad . \quad . \quad (12)$$

where p = distance flown in a particular time interval, expressed as a proportion of the total distance flown during the flight
h = altitude correction factor appropriate to the average altitude in the time interval
f_m = mean stress appropriate to time interval.

Values of h are given in Fig. 3. For continuous cruising over land a reduced altitude correction factor is used to allow for the pilot's discrimination in avoiding turbulence. At low altitudes over the sea it is permissible to assume gust frequencies lower than over land. For flight over mountainous country the height above average ground level should be used instead of height above sea level.

The factored damage per hour of typical flight is given by:—

$$D_T=\frac{DV}{10^6}$$

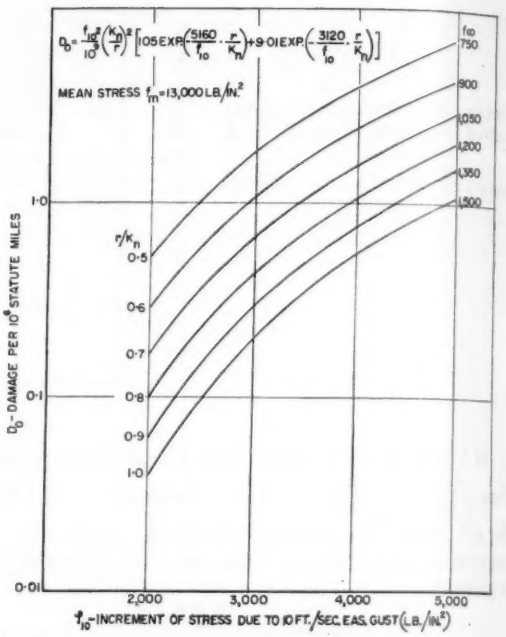


FIGURE 5. Damage curves for standard gust spectrum.

and the factored damage per flight is given by:—

$$D_T=\frac{DVT}{10^6}$$

where V = average true air speed for the flight in m.p.h.
T = duration of flight in hours.

10. Allowance for Ground-to-Air Loads

To assess the effect of the ground-air-ground cycle, a separate test may be required but it is more usual for the appropriate load range to be combined with that representing turbulence. The latter procedure is often adopted in full scale wing fatigue tests, where the test loading simulates a typical flight by applying representative ground-air loads once per flight, together with a sufficient number of gust loads to represent the average fatigue damage per flight due to turbulence.

When ground-air loads are covered by a separate test, the damage due to the ground-air cycle must be added to that due to turbulence. It is suggested that a factor of 3 on endurance should be used to cover scatter of fatigue performance under ground-air loading together with a factor of 1·2 to cover variation in taxying conditions. The factored damage per flight due to this loading is then given by

$$D_G=\frac{3{\cdot}6}{N_G}$$

where N_G = endurance of component under representative ground-air loading.

The total factored damage per flight is given by $\frac{DVT}{10^6}+\frac{3{\cdot}6}{N_G}$ and the safe life by

$$\frac{1}{\frac{DVT}{10^6}+\frac{3{\cdot}6}{N_G}} \text{ flights} \quad \text{or} \quad \frac{T}{\frac{DVT}{10^6}+\frac{3{\cdot}6}{N_G}} \text{ hours.}$$

When ground-air loads are combined with gust loads in a test, the resultant endurance should be applied directly to the procedure outlined in Section 9.

11. Numerical Examples

Two numerical examples are given in Appendix II to illustrate the method of calculation. The first example is of a medium range air liner designed to static strength requirements, with no particular attention paid to fatigue in the design stage. The second is a calculation for a short range freighter aircraft designed against fatigue.

12. Conclusions

The estimation of safe fatigue life depends on the assessment of the cumulative damage arising from the loads encountered by the aircraft, with a sufficient margin of safety to ensure that the chance of failure is remote.

A simple method has been derived for the assessment of the safe fatigue life of transport aircraft wings, based on generalised gust data and on endurance curves predicted from a limited number of fatigue tests. Provided that tests are carried out at a load level reasonably close to that corresponding to the maximum rate of fatigue damage, serious errors are avoided. For aircraft designed to low working stresses, the appropriate load level may be higher than the 10 ft./sec. gust criterion which has been widely used in the past. It is suggested that for aluminium alloy structures an over-riding minimum alternating stress of 3,500 lb./in.^{2} should now be added to this criterion.

The safe life can be predicted from the average life of a particular component by allowing for scatter in load frequency and fatigue strength as follows:—

(*i*) a factor of 1·5 on gust frequencies is applied to cover operational variations, unless the actual load frequencies are measured on individual aircraft, in which case this factor becomes unnecessary,

(*ii*) a fatigue strength scatter factor is used to predict an endurance curve for a "weak" specimen, assuming a coefficient of variation of 0·10 on fatigue strength at all levels of load. The weak specimen is defined as one whose fatigue strength is three standard deviations below the mean.

Allowance must also be made for the loads arising during the transition from on-the-ground to in-flight conditions.

APPENDIX I

FATIGUE TESTS AT A SINGLE LOAD LEVEL

If the shape of the endurance curve for the particular component were known accurately it would not matter at what alternating load the tests were made. As the exact shape of the curve is not known, however, the test loading should be chosen to minimise errors which may arise from assuming a certain shape. For this reason it is desirable to test at a load level close to that corresponding to the maximum rate of fatigue damage.

In the past it was customary to test at a load corresponding to 7½ per cent of the fully factored load due to a 50 ft./sec. gust or, more recently, that corresponding to a 10 ft./sec. gust at an average cruising speed[8]. These criteria did in fact correspond reasonably closely to the most damaging load level for most transport aircraft which had been designed wholly on static strength requirements. For aircraft which have been designed to reduced stresses to give a longer fatigue life, however, the 10 ft./sec. gust criterion becomes unrealistic, as it may give loads which are well below the most damaging level.

In Figs. 6 and 7 the variation of damage rate with alternating stress and gust velocity are given for two cases which may be taken as typical of (*a*) a wing designed to static strength requirements only and (*b*) a wing with reduced design stresses to give long fatigue life. These curves are based on the "average joint curve" for light alloy structures. It will be seen from Fig. 6 that in case (*b*), where the 10 ft./sec. gust stress is 2,000 lb./in.^{2}, the 10 ft./sec. gust is well away from the most damaging level. At such low alternating stresses, moreover, the endurance curve is very flat and serious errors could arise from using a single point on this part of the curve to predict the complete endurance curve.

In Fig. 8 the most damaging stress level and the most damaging gust velocity are plotted against the stress corresponding to a 10 ft./sec. gust. In order to minimise the errors it is desirable to test at the most damaging level, but in practice this is not possible since the point of failure and hence the stress at the critical section are not known until tests have been made. It is suggested, therefore, that the test should be made at a load level of not less than that corresponding to the most damaging load predicted from the average endurance curve, associated with the net stress across the most probable section of failure, *i.e.* the minimum cross section. It is further suggested that for light alloy structures there should be a lower limit of 3,500 lb./in.^{2} for the alternating stress applied on test, to avoid testing on the flat part of the endurance curve. This has the incidental advantage of shortening the test. In practice the stress corresponding to a 10 ft./sec. gust is likely to be between 2,000 and 4,000 lb./in.^{2}

A simple criterion which largely satisfies the requirement that the load level should be somewhere near the most damaging level and at the same time that the alternating stress should not be too low, may be stated as follows:—

For light alloy structures, the alternating load shall be either that corresponding to a 10 ft./sec. E.A.S. gust at an average cruising speed, weight and fuel distribution or that load which will give a stress of 3,500 lb./in.^{2} on the net cross sectional area, whichever is the greater.

The mean load for the test is the average 1*g* load for a typical flight. In accordance with established practice the specimens are first preloaded to twice this load.

APPENDIX II

NUMERICAL EXAMPLES TO ILLUSTRATE THE METHOD OF CALCULATION

1. EXAMPLE 1. MEDIUM RANGE TRANSPORT

1.1. *Average operating conditions*

The average flight duration is 4 hours and the aircraft cruises at 200 kt. E.A.S. at 20,000 ft. The flight profile has been broken down into various stages in the climb, cruise, descent, stand-off, and approach phases of the flight. The appropriate speeds and time spent in each height band are given in columns (1) to (6) of Table II.

1.2. *Stresses*

The stresses due to a 10 ft./sec. E.A.S. gust at the critical section of the wing are indicated in columns (9) and

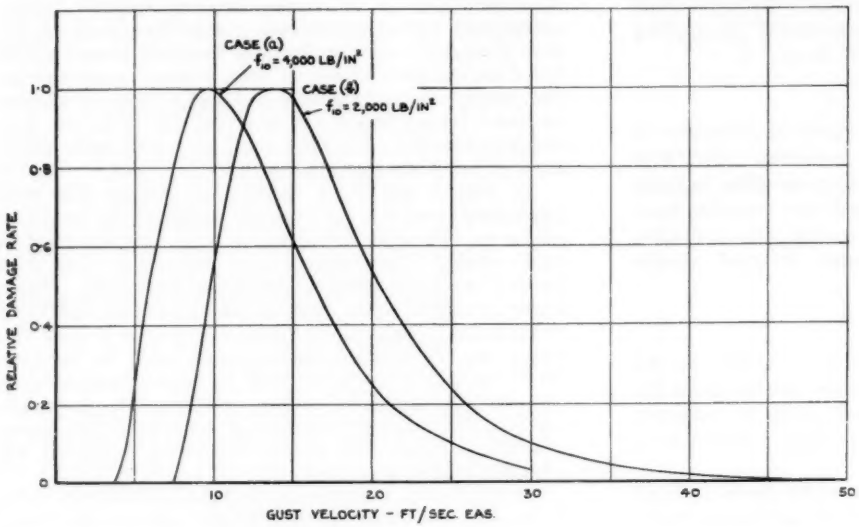


FIGURE 6. Variation of damage rate with gust velocity.

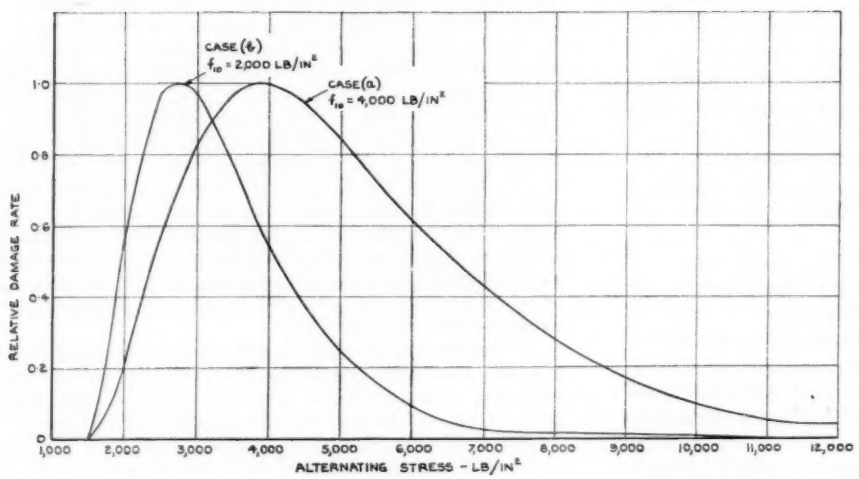


FIGURE 7. Variation of damage rate with alternating stress.

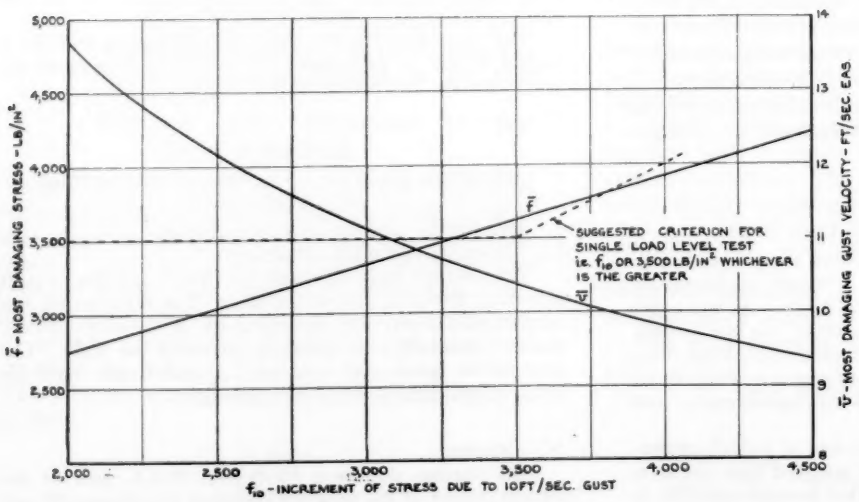


FIGURE 8. Variation of most damaging stress and gust velocity with f_{10}.

TABLE II

CALCULATION OF SAFE FATIGUE LIFE FOR MEDIUM RANGE TRANSPORT

(1) Phase of flight	(2) Height band (ft.)	(3) Average height (ft.)	(4) Speed (Kt. EAS)	(5) Speed (Kt. TAS)	(6) Time in height band H	M	(7) Distance travelled (N. miles)	(8) Proportion of total distance p	(9) Stress due to 10 ft./sec. gust f_{10} lb./in.²	(10) 1g Mean stress f_m lb./in.²	(11) Damage per 10^6 miles (std. gust spectrum) for f_m = 13000 (from Fig. 5) D_0	(12) Altitude correction factor h (Fig. 3)	(13) f_m/13000	(14) Total gust damage in height band per 10^6 miles. (11)×(12)×(13)×(8)
Climb	0-5000	2500	160	166		6	17	0·017	3100	15000	1·18	2·0	1·15	0·0461
	5000-10000	7500	160	179		6	18	0·018	3100	15000	1·18	0·62	1·15	0·0152
			160	194		6	19	0·019	3000	15000	1·05	0·22	1·15	0·0051
	10000-150000	12500	160	210		8	28	0·027	3000	15000	1·05	0·081	1·15	0·0026
	15000-20000	17500												
Cruise	20000	20000	200	274	1	0	274	0·271	3600	15000	1·80	0·04	1·15	0·0195
	20000	20000	200	274	1	0	274	0·271	3500	14000	1·65	0·04	1·08	0·0193
	20000	20000	200	274	1	0	274	0·271	3400	13000	1·52	0·04	1·00	0·0190
Descent	20000-15000	17500	180	237		6	24	0·024	3300	13000	1·40	0·081	1·00	0·0027
			180	218		5	18	0·018	3300	13000	1·40	0·22	1·00	0·0055
	15000-10000	12500	180	201		5	17	0·017	3200	12000	1·29	0·62	0·92	0·0125
			180	187		5	16	0·016	3200	12000	1·29	2·0	0·92	0·0380
	10000-5000	7500												
	5000-0	2500												
Stand off	2000	2000	150	155		10	26	0·025	2700	11000	0·76	2·4	0·85	0·0387
Approach	1000-0	500	120	121		3	6	0·006	2200	11000	0·39	5·0	0·85	0·0100
				Total	4	0	1011 N.M.	1·000						0·2342

=1163 St.M

V=average TAS=253 Kt.
=291 m.p.h.

r/K_n=0·6.

From equation (12)

Total factored gust damage per 10^6 miles = 1·275×0·2342
= 0·299

Total gust damage per flight = $\frac{0·299 \times 1163}{10^6}$
= $3·48 \times 10^{-4}$

Factored damage per flight due to ground-air loads = $0·18 \times 10^{-4}$

Total damage per flight = $3·66 \times 10^{-4}$

Therefore safe life = 2730 flights

or Safe life = 10,920 hours

(10) of Table II for the various phases of the flight. These are the resultant stresses on the net cross sectional area taking into account the variation of bending moment with change of weight, fuel and speed throughout the flight.

1.3. *Fatigue tests*

Tests have been carried out on a number of components:—

(*a*) under a loading to represent turbulence, with a mean stress of 14,000 lb./in.² and an alternating stress of 3,500 lb./in.² Geometric mean endurance of six tests=334,000 cycles.

(*b*) under a loading representing the average ground-to-air load range that occurs once per flight. Mean endurance 200,000 cycles.

1.4. *Calculation of fatigue damage*

Table II gives details of the calculation of damage due to turbulence using the method described. The geometric mean endurance corrected to a mean stress of 13,000 lb./in.² is 360,000 cycles. The corresponding stress on the "average joint curve" (Fig. 4) is 4,000 lb./in.², hence r=3,500/4,000=0·875. K_n for six specimens is 1·45 (Table I), hence r/K_n=0·6 and the damage is read off the appropriate curve of Fig. 5. The factored damage per flight due to ground-air loading is given by

$$D_G = \frac{1·2 \times 3}{200,000}$$

$$= 0·18 \times 10^{-4}.$$

TABLE III

CALCULATION OF SAFE FATIGUE LIFE FOR SHORT RANGE FREIGHTER

(1) Phase of flight	(2) Height band (ft.)	(3) Average height (ft.)	(4) Speed (Kt. EAS)	(5) Speed (Kt. TAS)	(6) Time in height band (Mins.)	(7) Distance travelled (N. miles)	(8) Proportion of total distance p	(9) Stress due to 10 ft./sec. gust f_{10} lb./in.^{2}	(10) 1g Mean stress f_m lb./in.^{2}	(11) Damage per 10^6 miles (std. gust spectrum) for f_m=13000 (from Fig. 5) D_0	(12) Altitude correction factor h (Fig. 3)	(13) f_m/13,000	(14) Total gust damage in height band per 10^6 miles. (11)×(12)×(13)×(8)
Climb	0-1000	500	160	161	3	8	0·088	2200	9000	0·145	5·0	0·692	0·0442
Cruise	1000-2000	1500	180	184	22	68	0·747	2500	9000	0·228	2·0	0·692	0·2350
Descent and Approach	1000-0	500	180	181	5	15	0·165	2500	9000	0·228	5·0	0·692	0·1300
				Total	30 min.	91 N.M.	1·000						0·4092

=105 St.M.

From equation (12)

Total factored damage per 10^6 miles $=1{\cdot}275\times0{\cdot}4092=0{\cdot}521$

Total damage per flight $=\dfrac{0{\cdot}521\times105}{10^6}$

(Ground-air effects have been included in fatigue tests) $=5{\cdot}47\times10^{-5}$

$r/K_n=0{\cdot}8$. Therefore Safe life $=18{,}300$ flights

or Safe life $=9150$ hours.

This is added to the damage due to turbulence and the resultant safe life works out at 2,730 flights or 10,920 hours.

2. EXAMPLE 2. SHORT RANGE FREIGHTER

2.1. *Average operating conditions*

It is assumed that the aircraft is used on high intensity short range freighting with an average duration of flight of 30 minutes and a cruising height of between 1,000 and 2,000 ft.

2.2. *Stresses*

The wing has been designed to relatively low stresses to give a reasonable fatigue life. 1g and 10 ft./sec. gust stresses are given in columns (9) and (10) of Table III.

2.3. *Fatigue tests*

Tests have been carried out on three representative specimens of the wing structure. The test loading represented an average 1g net stress of 9,000 lb./in.^{2} with an alternating stress of 3,500 lb./in.^{2} Ground-to-air loads were also included in each test, based on a 30 minute flight. The geometric mean endurance of the three tests was $1{\cdot}45\times10^6$ gust load cycles. With a K_n of 1·48, this gives a value of $r/K_n=0{\cdot}8$ for use in Fig. 5.

Since ground-to-air loads were included in the fatigue tests no further allowance is necessary in this case.

The safe life for this aircraft is 18,300 flights or 9,150 hours.

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A Review of Current Developments in Agricultural Aviation

BY

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THE INCREASING IMPORTANCE of agricultural aviation can best be judged by a table setting out the area treated in the U.S.A., U.S.S.R., U.K. and other countries, which was compiled from recent publications. Fig. 1 shows how important a sector of aviation agricultural aviation has become.

Like other aircraft operations, agricultural aviation is not particularly profitable. Therefore a certain amount of work has gone into economic studies and into development work on methods for improving the service rendered to agriculture in order to improve the economy of aircraft operation.

As agriculture is making very slender or no profits in peacetime, farmers are not interested in agricultural aviation *per se* but only in better returns from their crops and they therefore consider using aircraft services only when:

(*a*) the job cannot be done any other way and
(*b*) when aircraft can do the job more cheaply and efficiently.

Aircraft are often more efficient in producing a better or more timely control of pests because under good conditions they give higher output, greater flexibility and are independent of ground conditions.

There are many types of agricultural aviation—sowing, fertiliser spreading and the control of pests, plant diseases and weeds.

This Society has recently heard an excellent address on the control of locusts by Dr. Rainey and I will therefore not deal with this important section of agricultural aviation which has rendered such a great service to agriculture overseas. I shall also omit aerial spraying for the control of public health pests which are dealt with by space spraying, but propose to concentrate on agricultural aviation in Western Europe, and in particular in this country where special problems have so far precluded its expansion to the size attained in the U.S.A., U.S.S.R. and New Zealand.

Agricultural aviation has taken over certain aspects of farming from tractor-operated equipment, in particular the distribution of fertilisers, the control of pests, plant diseases and weeds and sowing on very wet soil. Nevertheless, tractor-operated equipment still forms, in many cases, an alternative to aerial spraying and therefore has a depressing influence on the prices which aerial spraying contractors can obtain. Thus a current review of agricultural aviation would be incomplete without mentioning the advances in ground spraying equipment designed to encroach on aerial spraying services. Recent such advances are:

1. The use of extra narrow row crop tyres on tractors and sprayers which are only 7 in. wide and thus enable the treatment of standing crops with less damage;
2. The use of mist blowers in agriculture which have a swath width of up to 60 ft.
3. The use of high clearance tractors which are being mass produced for cotton but can clearly be used on tall crops, such as Brussel sprouts, in this country.
4. The application of pesticides in granular form simultaneously with routine farm operations.

The continuous pressure on farming economy caused in the U.K. by the annual price review, which nowadays leads more often than not to the reduction of price support, makes aerial spraying unacceptable unless it shows advantages to the farmer.

The economic factors which affect agricultural aviation have been very ably set out in a paper by Norman[44] at the First International Agricultural Aviation Conference which was held in this country in 1959.

This paper is an important contribution to the understanding of the economic factors in that Norman gives a computation of the cost per productive hour, excluding the interest on capital. In Fig. 2, I have extended his table to compare costs for fixed wing aircraft, the autogyro, the helicopter and the air spraying robot (all data on the latter type of equipment are merely design objectives, not yet performance data).

Using these figures, we can then extrapolate from his graph the cost per acre at different work outputs (Fig. 3) and different costs per hour.

A graph of the effect of utilisation hourly cost (Fig. 4) shows that the agricultural aviation operator takes a considerable risk in our variable climate of not obtaining full utilisation, which immediately puts him at a loss. If he does, however, have a normal working load, then

*The 13th Lecture to be given before the Agricultural Aviation Group of the Society———on 19th April, 1961.

Country	*Year*	*Acreage treated (millions)*
U.S.A.	1957	61·3
U.S.S.R.	1959	49·9
Canada	1957	6·8
Australia	1960	5·0
New Zealand	1958	4·5
Africa	1959	2·8
China	1959	2·5
Latin America	1958	2·1
Europe (O.E.E C. area)	1959	1·4
Europe (Satellite area)	1959	0.4
Asia except: U.S.S.R. and China	1958	0·3
World	estimated	145

FIGURE 1. Areas treated by Agricultural Aviation.

there is a profit margin, but alas it is not high; in the United Kingdom during the past few years an average charge amounted to less than £1 for fertiliser top dressing; not more than 15/- per acre for crop spraying; and not more than 25/- for helicopter spraying.

This obviously is not a sound economic position and I have therefore taken it as my task in preparing this review of current developments in agricultural aviation to screen the recent contributions, in order to select those which will enable the agricultural aviation operator to work more effectively and, therefore, more profitably.

Agricultural aviation can expect a higher reward if by increased efficiency it can produce for the farmer a better return on his crops. This means timing the operation more accurately and, in crop spraying, improving on the biological result.

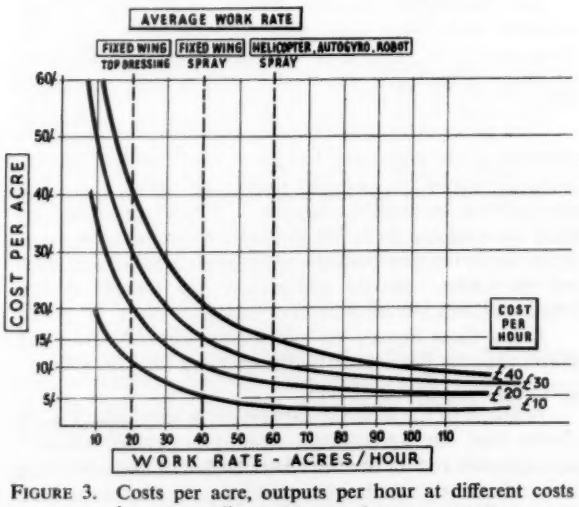

FIGURE 3. Costs per acre, outputs per hour at different costs per hour (according to Norman but augmented).

		Fixed wing	*Helicopter*	*Autogyro*	*Robot*
1	Aircraft annual fixed costs	4·30	16·00	5·10	5·30
2	Aircraft hourly variable costs	3·96	4·37	3·96	4·26
3	Pilot cost	4·63	4·63	4·63	—
4	Ground support cost	4·03	4·03	4·03	4·03
5	Marking cost	2·52	2·52	2·52	—
6	Overhead and administration	2·86	2·86	2·86	2·86
	£	22·30	34·41	23·10	16·45

FIGURE 2. Cost per productive hour (in £) based on 400 hours of productive flying (according to Norman, but modified for Autogyro and Robot).

The agricultural aviation operator can improve the economy of his operation by using new types of aircraft which have a higher performance and/or by a better utilisation of the spraying aircraft through an extension of the number of services which he renders to the farmer at the beginning and end of the spraying season.

Possibilities for increasing the return from investment in aircraft by better performance of new aircraft

Time study into the factors influencing the performance of spraying aircraft per hour has led Professor Baltin to a formula by which the performance per hour of any campaign can be calculated fairly accurately. Amsden has transposed this formula into British units (Fig. 5).

The Baltin formula[5, 6] gives interesting pointers to

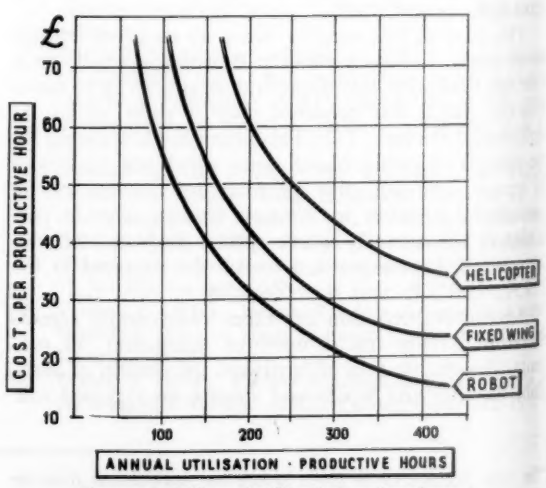

FIGURE 4. Effect of utilisation on hourly cost.

$$\text{minutes/acre} = \frac{TrQ}{Qf} + \frac{165}{bv} + \frac{4840\,Tw}{60bL} + \frac{120aQ}{VQf} + \frac{60C}{VF}$$

$$\text{or } T = Tr + \frac{165Qf}{Qbv} + \frac{4840\,TwQf}{60QbL} + \frac{120a}{V} + \frac{60CQf}{VFQ} \text{ (minutes)}$$

Tr minutes spent on ground (filling and servicing).
Q gallons/acre required dosage (or lb.).
Qf gallons spray carried per load (or lb.).
b swath width in yards.
v spraying speed in miles/hour.
Tw turning time in seconds.
a distance airstrip to fields in miles.
V ferrying speed in miles/hour.
C distance between fields in miles.
F area of field in acres.
T minutes per spray cycle $= tQf/Q$.
t efficiency (minutes/acre).
L length of field in yards.

FIGURE 5. Baltin-Amsden formula.

the factors which are important in the assessment of the candidates for the aircraft best suited to agricultural aviation.

The controversy about the respective advantage of the helicopter and the fixed wing aircraft has now been settled. The claims which have been made for the helicopter[20, 21, 28, 29, 34, 49, 50]—that it produces a down wash which gives a better penetration and therefore a higher deposit of the spray chemicals is valid, but only for speeds of up to about 35 m.p.h. Where the helicopter has to compete with the aeroplane on agricultural aviation jobs, the helicopter has on larger fields to be flown so fast that there is little difference in its down wash on the crop compared with a fixed wing aircraft. What is important is that the helicopter can land near to the spraying site, thus has shorter ferry flights (a) and less turning time (Tw) hence a higher output per acre. The same applies to the autogyro, which in addition should cost approximately half when suitable machines are produced in quantity.

The helicopter sprayer is therefore only more efficient as a sprayer where it is economic to fly slowly, namely in the control of pests in orchards, vineyards, seed crops and hopfields. There its advantages are outstanding and surpass those of any other aircraft.

My patent of 1944, the work together with Tudor[49], the early developments of the helicopter sprayer at Pest Control Ltd., together with research by Hill[28] and by Dutch investigators, as yet unpublished, outline the limitations of the superiority of the spray 'copter over the spray 'plane at slow speeds. At speeds of less than 35 m.p.h. there is considerable turbulence of the downwash causing movement in the crop which is responsible for the higher spray deposits obtained, and which is now being exploited in research for the treatment of vineyards in France by a working party of the International Agricultural Aviation Centre.

For standard agricultural spraying operations, at a speed of 50 m.p.h., the helicopter loses this better effect and has found it difficult to maintain more than a small sector of agricultural aviation work because its advantages arising out of the much shorter turning time and ferry flight are slightly outweighed by its higher capital and increased maintenance cost. These disadvantages are not shared by another rotary wing aircraft, the autogyro, which also has much slower turning times and

Aircraft	*Cost £*	*Spray load* gal.	kg.	*Capital cost per gal.*
Piper Pawnee	2,300	90	400	25·77
Snow S.2	2,900	135	600	21·5
Hiller Helicopter	22,000	50	220	440
Kolibri H3	8,500	44	200	195
Djinn	13,200	44	200	305
Umbaugh 18 Autogyro	4,500	33	150	135
Robot Sprayer	est. 5,000	22	100	227

FIGURE 6. Capital cost per gal. spray load carried.

very much shorter ferry flights. Practical experience and the Baltin-Amsden formula show that the autogyro is to-day the most promising aircraft for agricultural aviation. When I think back that I had my first experience of aerial spraying 24 years ago with autogyros in 1937 in Everglades, Florida, the wheel seems to have turned full circle.

Likely candidate aircraft were analysed by calculating the capital cost per sprayload carried (Fig. 6). Of the new aeroplanes which have been developed for agricultural aviation, I want to discuss only two. The ultimate in safety to the pilot and accident prevention is described in a paper by Weick on the "Design Philosophy of the Agricultural Airplane"[58]. Weick has developed an aeroplane from his work at the Texas A & M College with the Ag-1 and the design philosophy expounded by him, which incorporates many parts common with other Piper Aircraft and is called the PA-25 "Piper Pawnee."

Another development of the Ag-1 is the "Snow." The latter is superior to the Piper Pawnee from the point of view of load carrying capacity (Qf).

As far as protection to the pilot in a crash is concerned, both aircraft are a great advance: they seat the pilot above and behind the load, the fuselage is stressed in such a way as to resist normal crash loads and provisions are made for the distribution of energy in a crash by progressive collapse.

Of still greater economic importance to the aircraft operator is the critical influence on the cost of operations caused by accidents resulting from the hazardous form of flying which agricultural aviation entails. To this end, the new aircraft provide for a decrease in the likelihood of accidents through an ample field of view and satisfactory lateral control at the lowest speeds, together with wire-cutting devices which will get the aircraft through wires with the minimum retarding or deflecting effect.

Pilots who have flown the Piper Pawnee are quite ready to agree that Weick has more than made good all the implementations of his design objectives, but the aircraft with its 150 h.p. engine is underpowered. The Snow S-2 with its 220 h.p. engine and larger chemical dispersal load seems to be the best of the new aeroplanes specially designed for agricultural aviation.

As far as helicopters are concerned, the best value for spray load carried is the Kolibri, a ram jet helicopter of

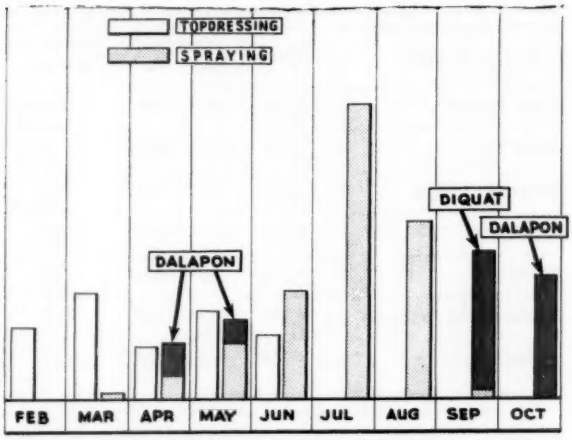

FIGURE 7. Proportion of top dressing to spraying in the U.K. 1959 (according to Norman, but augmented by Dalapon and Diquat applications).

great simplicity and easy maintenance[9, 46]; it might well become the best tool for those special operations where the helicopter's advantages over the aeroplane and the autogyro outweigh its higher cost penalty, always provided that no additional air for atomising nozzles is required.

Of the autogyros, the Benson would seem to be not yet sufficiently reliable an aircraft to fulfil the great expectations recently shown for autogyros. Its load carrying capacity is so small that it can carry only enough for about 4 acres with a light pilot, but work is in progress in this country on the production of a version suitable for agricultural purposes (Napier-P.B.I. agricultural gyroplane).

I expect that we shall see in autogyros further development for agricultural aviation and the pay-off for the research work put into rotary wing aircraft for crop spraying and fertiliser spreading.

In brief, of the agricultural aircraft, the aeroplane still leads the field. Its long ferry flight and long turning time make its performance far less superior to the rotary wing aircraft than its much lower capital cost per chemical load would suggest. If the autogyro performs as well as the helicopter, it will at its much lower capital cost per chemical load soon constitute a powerful challenge to the fixed-wing aeroplane.

What additional spraying services could the aerial spraying contractor add to his range in order to increase the utilisation of the aircraft?

If we revert to the paper by Norman[44] and start off with his histogram showing the proportion of top dressing and spraying done in each month in the U.K., we observe that anything which can be done outside the July/August peak would be very desirable to increase utilisation and thus bring in more revenue. Two pesticides which have recently been introduced in this country would be useful for such additional work. These are diquat and dalapon. (Fig. 7).

Diquat, under the trade name of Reglone* is used to burn off the potato haulm. It is non-corrosive and non-toxic and could be sprayed by aircraft on potatoes when blight infestation has become rampant. Up till now haulm killing has been carried out with sulphuric acid and sodium arsenite, but owing to a lethal accident with sodium arsenite, the agricultural chemical industry has undertaken to discontinue the sale of this haulm killer.

Aerial application of the new haulm killer Reglone has many advantages over ground spraying; it is very quick and when blight really strikes the farmer obviously wants to destroy the haulm as quickly as possible. As a sizeable percentage of the potato acreage is already treated by aerial spraying of copper fungicides, this additional service would cost little in the way of sales costs and, indeed, adequately complements the fungicide applications.

Plant Protection Ltd. made trials with Reglone in 1960 using the Auster spray aeroplane and a Bell helicopter sprayer, applying 1½ lb. diquat in 2 gals. by aeroplane and 4 gals. by spray 'copter. The leaf and stem destruction was as good as obtained by ground spraying with 1½ lb. diquat in a considerably larger volume of water[45].

Dalapon† has three different new uses.

1. In pasture renovation it has been demonstrated that 5–10 lb. of Dowpon‡ grass killer will kill or suppress unthrifty grass sward so that it can be oversown with a more palatable and more productive grass species, supplemented by an application of fertiliser.

This method of pasture renovation is practised in New Zealand on some scale[8] and is called "chemical ploughing." The West of Scotland College of Agriculture, the Hill Farming Research Station and Dow Agrochemicals have demonstrated that this method of pasture renovation is also practicable in this country and together with fertiliser dressing quickly improves the stock-carrying capacity of pasture. This, for once, is a service where in many locations there is no competition from ground methods because the renovation of pasture by Dalapon spraying and fertiliser dressing can only be done from the air.

The slow changes of the unthrifty grasses to fodder grasses by ground methods takes four to five years, but by aerial spraying of Dalapon, aerial oversowing and aerial fertilising, the same effects can be obtained in one year. The Scottish Colleges of Agriculture, the Hill Farming Research Station, the Grassland Offices of the N.A.A.S. and my company, Dow Agrochemicals Ltd., have done most of the development work and demonstrations have been held to show what can be achieved by this technique.

2. By far the largest application of Dowpon in this country is for the control of couch grass on stubbles in September and October. This is in a normal year carried out by tractor spraying machines, but where the farm has a large acreage of root crops this treatment clashes

*Trade mark of Plant Protection Ltd.

†A common name for dichloropropionic acid in the U.K., U.S.A. and Canada and in many other countries abroad a trade mark of The Dow Chemical Company.

‡Trade mark of The Dow Chemical Company.

with the root crop harvest. Many farmers would prefer an aerial application, were it inexpensive.

In a wet Autumn like that of 1960, farmers were simply unable to carry out their Dalapon treatment although their land was very badly infested with couch and this perennial grass very much increased its hold on the land in that wet autumn. In a wet year aerial spraying of Dalapon is the only practical method of couch control, but owing to the labour peak caused by the root harvest there will be some demand for couch control by aerial spraying every year. The application rate is 15 lb. of Dowpon in 4 gals. of water per acre.

Dowpon is a grasskiller and a drift problem might arise if the young Autumn cereals were already up. It is therefore desirable to carry out this treatment at the end of September and in October before the autumn cereals have germinated.

3. Reeds in water courses, ponds and lakes can be eradicated by Dowpon. In many locations this can only be done by aerial spraying because of the swampy nature of the ground and the lack of open water for operating a boat. Application of 25 lb. of Dowpon in 5 gals. of water has been very successful against the common reed *Phragmites communis*.

Can modern technology improve the biological effect of the pesticide by better dispersal or more effective deposition on the crop?

Engineers and biologists concerned with the atomisation of liquids for crop protection purposes have been attracted by the tremendous increase in the area of sprayed surface covered by a given volume of liquid if it is more finely dispersed.

This, however, cannot be carried to its attractive extreme because there are two factors operating against this theoretical spray cover being obtained in practice. With decreasing droplet diameter the terminal velocity of droplets decreases so much that the proportion still airborne outside the area to be sprayed becomes too large. Yeo[63, 64] found that for low flying aircraft sprays with volume median diameter exceeding 200μ, recoveries of the spray chemical on the treated foliage are usually 80 per cent, within very short distances down wind; with finer sprays, of volume median diameters of 150μ, recoveries within a few tens of metres are usually 50–60 per cent only.

As the finer droplets settle slowly they have more time not only to drift away, but also to evaporate. Thanks to the work of Yeo[60, 64], Courshee[17, 19] and others, the parameter of useful droplet sizes is well understood. For the aerial spraying of agricultural crops in the U.K. droplets of volume median diameter of much less than 200μ are inadequate and may be dangerous.

To assess the droplet size their number in various size ranges of the spectrum of droplets is measured and from these measurements a constant is calculated expressed either as the median diameter of all the spray droplets en masse, or as the diameter in μ of a single droplet with the same ratio of surface to volume as the entire spray; Sauter diameter, *SMD* or *D*.

Hydraulic, rotary and air blast nozzles are used to break the spray liquid into fine droplets.

In the hydraulic nozzle the spray fluid is formed into a thin film at the nozzle orifice which is shattered.

When the spray nozzles face the direction into which the aircraft is moving, the resultant speed of the liquid relative to the air is the sum of the air speed and the liquid speed of the nozzle. Thus a finer spray is formed than when the nozzle points downwards. Kruse, Hess and Ludvik[38] have shown that the droplet size increases further if the nozzles are pointed towards the back.

It is well established that rotary atomisers produce a more uniform droplet spectrum; Hill[30] compared a rotary cage Micronaire atomiser, a multiple rotary disc unit and a rotary brush, which all gave more uniform droplet size than the hydraulic spray nozzle.

Trannoy[57] has designed an interesting air blast nozzle device in which it is possible to vary the output and droplet size independently of each other. The output is varied by the pressure cushion over the spray liquid in the pneumatic tank and the droplet size by the volume of air which is ducted to the nozzle.

In air blast nozzles an auxiliary supply of air is used to blast a stream of slowly moving liquid to pieces. Fraser[23] has shown that one kilo of air is needed for each kilo of liquid, hence the power consumption of air blast nozzles is greater than that absorbed by hydraulic nozzles.

Their advantages are their much larger orifices compared with hydraulic nozzles, so that they need not block and secondly, they can be designed to give a very fine spray, which is desirable for space spraying against flying insects[60].

Behind the propeller of a fixed-wing aircraft there is a turbulent, asymmetrical rotational movement of the air[14], which has been elegantly demonstrated by Akesson and Yates[1] using weightless balloons. This has a considerable influence on the spray pattern produced by a boom sprayer.

As far as spray nozzles are concerned, the uneven deposit owing to turbulence can be overcome by massing the spray nozzles in the position where the strongest propeller slip stream hits the boom. This propeller vortex is more difficult to counteract when rotary atomisers are used and Courshee[18] therefore contends that the spray distribution of rotary atomisers is strongly affected by the vortex characteristics of the spray aeroplane. From this point of view the rotary atomiser is inferior to the boom sprayer.

According to Akesson and Yates[1] neither rotary atomisers nor nozzles should be placed within three yards of the wing tips so as not to be carried aloft by the wing tip vortices. It has been suggested that one way of reducing drift would be to devise smaller rotating atomisers, of which one could have a number, in place of spray nozzles.

What droplet size is most useful for aerial spraying?

Kerssen[36] and Courshee[18] have demonstrated that low volume application with droplets of a Sauter

mean diameter of 200μ are inadequate to protect the crop against fungus diseases or insects located in a hidden position on the plant, but the aerial sprayer relies on a re-distribution of the pesticide deposit. This is not a new concept but it has become much more clearly understood in its quantitative importance in recent years.

Let us first consider the case where there is no re-distribution. Amsden[2] described at the First International Agricultural Aviation Conference how on cotton in the Sudan, if one leafhopper were placed on a leaf with only one droplet containing a lethal dose of DDT, the insect remained alive without ever contacting the droplet insecticide. Even 10 droplets or 100 droplets per leaf were insufficient to ensure that one insect picked up a lethal dose before it became adult and flew away unharmed. Something of the order of 1,000 droplets per leaf were needed to ensure death. But when two or more leafhoppers were placed on the same leaf the activity of the leaf hoppers became noticeably greater and the mortality was considerable with only 100 droplets per leaf. Thus, even with a number of leafhoppers, a sizeable number of droplets per leaf are necessary to ensure a high degree of mortality. The disastrous lack of control of the jassid by spraying in parts of the northern Gezira in the Sudan in 1960 was caused by inadequate attention to this important factor.

As will be seen in a discussion of the drift problem, Courshee and Ireson[19], Courshee[17] and Yeo[63] have demonstrated that droplets with an *SMD* of 200/250μ drift very little and this is a safe and useful size. Having then not quite so many, and larger, droplets we rely on a biological action of the pesticide at a distance, either by gaseous effects or by re-distribution of the pesticide deposit either in or on the plant surface.

Systemic pesticides are translocated in the leaf which makes a high degree of mortality possible with a similar number of droplets than are necessary for contact insecticides which are not re-distributed; here again one must not over-estimate the translocation in the plant and it is necessary that adequate numbers of droplets are deposited per leaf, in order to obtain adequate translocation of the systemic pesticide.

Systemic insecticides are ideal for aerial spraying and are widely used. Similarly, translocation in the plant is exploited in the use of weedkillers, such as plant hormones and Dalapon, to obtain a good control of the weeds.

As far as fungus diseases are concerned, Horsfall[31], Moore[42], Morgan[43], Courshee, Daynes and Byass[15], demonstrated a long time ago that the radius of action of a fungicide droplet was larger than its actual deposit and Kerssen[35, 36] and Courshee[16] have demonstrated that this is caused in copper fungicides for potato blight control by a re-distribution of the deposit through dew and rain. The ability of the copper to be re-distributed does not, according to Courshee[16], entirely remove the need for a good initial cover of a copper deposit. Courshee found that only 27 per cent protection is obtained per blight cycle with a type of spraying thought complete.

This in turn makes it unsurprising that the excessive use of stickers in order to produce rainfast fungicide deposits, decreases the fungicidal action of the copper preparation.

All this stresses the importance of careful supervision of the spray cover obtained on the various parts of the plant, which has recently become easier by the use of fluorescent methods for making droplets visible[40].

A fluorescent substance in very small quantities is added to the spray liquid; by looking at the deposits either in the dark using an infra-red lamp, or by the use of a daylight viewing chamber, the spray deposit is made visible.

The main obstacle to the wider application of aerial spraying in Europe

One of the greatest limitations to agricultural aviation in the United Kingdom is the drift hazard which will have to be overcome if agricultural aviation is to become a routine operation for the majority of pesticides in the United Kingdom and Western Europe.

This is an aspect of agricultural aviation where conditions in the tropics and North America are very different from ours. Our physicists, engineers and chemists will therefore have to make a unique contribution if agricultural aviation in Europe is to be applied to the same proportion of the area as in the overseas countries (*see* Fig. 1).

Thanks to the achievements of a number of research workers, both American and British, such as Courshee[19], Fraser[23] and Yeo[63, 64] the processes which lead to drift are now identified; I would like to discuss these first and, then, make proposals on how to overcome them.

American workers showed some time ago that increase in the flying height increases the drift hazard. Further, that with increasing wind speeds drift is intensified. These factors have been carefully worked out for drift spraying, which is used for the control of public health pests in many parts of the world, including the Arctic zone of Canada where A. W. A. Brown[12] has done excellent work.

Spray being caught in the wind tip vortices is an equally obvious source of drift, as has been previously mentioned under placement of nozzles and of rotary atomisers.

There is adequate evidence to show that if air spraying is done with even a light breeze, small droplets of 150μ and smaller remain airborne and are carried outside the field to be sprayed, causing contamination downwind. Figs. 8–10, taken from a recent paper by Yeo[64], make this clear.

Finally, the lack of a sharp cut-off at the spray end to the swath, and the creation of an upward slipstream by having to lift the aeroplane over the fence when turning over a neighbouring field, cause drift. I will not detail the more obvious causes of drift, such as dripping nozzles over neighbouring fields and other faults of which operators are well aware and which do not occur with modern British equipment.

Droplets smaller than 200μ are caused by two processes. In his recent lecture to the Agricultural Aviation Group of the Society, Fraser showed that at the

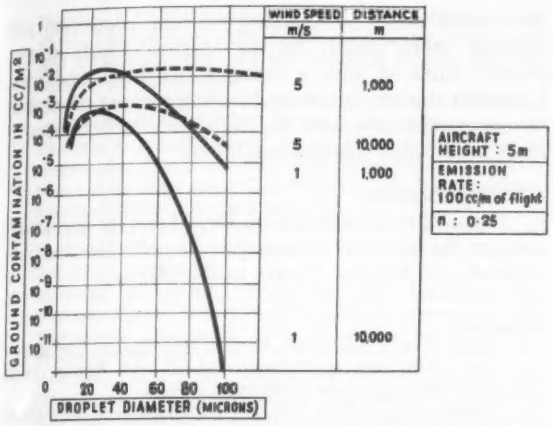

FIGURE 8. The contamination of the ground surface at distances of 1 km and 10 km downwind (according to Yeo).

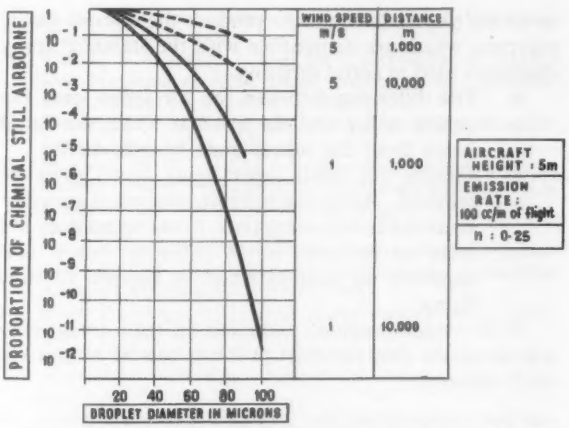

FIGURE 9. The proportion of chemical still airborne at distances of 1 km and 10 km downwind (according to Yeo).

orifice of a nozzle a sheet of liquid is formed which then breaks up. If it breaks up by forming ligaments, then satellites form from the necking on the disintegration of these ligaments into major droplets. Where the pressure of the liquid does not exceed two atmospheres, the break up of the liquid in front of the orifice is of this ligament type.

Where the liquid issues from the nozzle at above two atmospheres the spray sheet in front of the orifice becomes a wavy sheet because of turbulence in the sheet at the nozzle orifice and this sinusoid disintegration leads to the development of many satellites, which is even worse when spraying is carried out in other than still air conditions.

Fraser[23] has done no work on the kinetics of spray droplet formation when it is impacted with air, as would happen when an aerial sprayer discharges in flight, and his work refers only to still air conditions.

Coursheе[19] at the National Institute of Engineering has filled in these gaps and has explained the phenomenon, first observed by Kruse and collaborators[38] and already described, that the break up of the liquid into droplets is finer when the nozzle is pointed forwards rather than downwards, and that the break up of the downward pointed nozzles is greater than when the nozzle is pointed rearwards.

What can be done in practice to prevent spray drift?

1. Fly as low as possible—within 30 or 40 inches of the crop.
2. Turn over the field to be sprayed—and not over the neighbouring fields, *i.e.* use rotary wing aircraft.
3. Use rearward pointed nozzles and additives which impart visco-elastic properties to the sprayliquid were proposed by Fraser[23] and further investigated by Coursheе.

These additives accomplish two things:

(*a*) they suppress the turbulence in fine spray film produced at the nozzle orifice. This turbulence leads to the wavy sheet disintegration, but certain polymers act as an elastic damper on the tiny spray sheet which forms at the orifice of the nozzle, and therefore a ligament type break up of the spray sheet is produced, and not a wavy sheet disintegration.

(*b*) some of these additives avoid satellites by causing the necks of the subsidiary small droplets, when the form in the ligament break up, to withdrawn into the main droplet.

No stable spray formulation using these polymer chemicals is known to produce both these effects, but the phenomena as such have been demonstrated by Coursheе with *ad hoc* additions of polymers to sprays; it is now

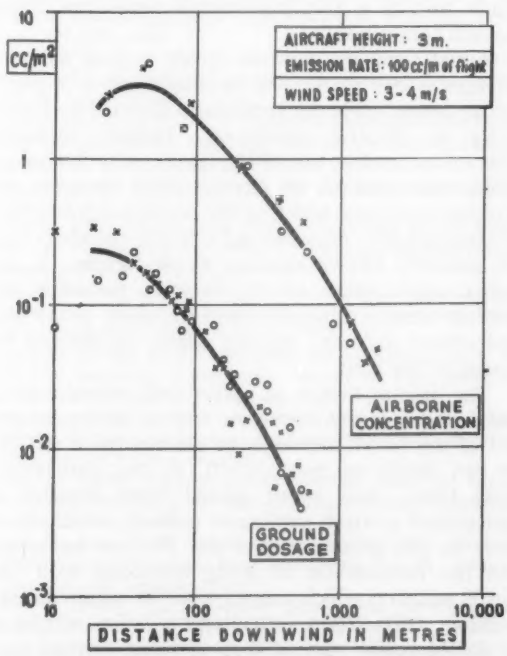

FIGURE 10. The drift downwind of a coarse aerosol with a volume median diameter of about 60 microns (according to Yeo).

up to the physical chemist to produce the desired elastic polymers which are compatible with the standard spray chemicals used in aerial spraying.

4. The difference between the air speed over the nozzle orifice and the speed at which the liquid issues from the orifice must be minimised.
5. Finally, on small fields flying speed must be reduced. As so much flying time when spraying small fields is turning time, lower speed does not form an insurmountable difficulty, but it presupposes an aircraft which is capable of slow flying.

With aerial spraying conducted on these lines, there is little doubt that the drift problem can be almost entirely removed.

The Future of Agricultural Aviation in the U.K.

Some are disappointed that farming from the air has not gone ahead as fast in this country as in some overseas territories and that farmers have not more enthusiastically embraced it; some are justifiably alarmed by the drift problem.

I think there is a very important reason why agricultural aviation ought to go ahead in the United Kingdom.

There is little farmers can do about the weather, which makes any agricultural operation in this country very risky. Unpredictable weather in Britain has in the past made it impossible to farm according to the book in any given year because an operation which is really adequate for coping with an extreme weather situation would lead to a very poor result under the opposite climatic conditions.

Aerial spraying, with its quick coping with large acreages is one of the first successful steps to free the British farmer from the inefficiency dictated by the wide swing in climatic conditions. Indeed, agricultural aviation is therefore one of the reasons why it would pay to do more research on farming more correctly under extreme conditions, which in this country requires the use of electronically programmed climate chambers which are generally known overseas as phytotrons. A much higher appreciation of the farming potential under extreme weather conditions and therefore of the use of agricultural aviation, can no doubt be derived from studies of this kind.

The limiting factors of agricultural aviation are cost and drift, but in this respect we seem to have come to the end of the wood, although we are not quite out of it; we can clearly see new aircraft, be they autogyros or, more likely, slow speed guided flight vehicles with agricultural aviation appliances (robots), which fly very close to the ground within the field to be sprayed; and the formulation of spray chemicals with viscoelastic additives which comply with the requirements for avoiding drifts. Then agricultural aviation will be able to do the major part of crop spraying services in this country and the majority of those fertiliser applications where ground or crop conditions do not permit it to be done otherwise. This will enable the British farmer to farm much better by adapting his crop protection and fertiliser more closely to the seasons which in this country show so wide a swing of climatic conditions. I consider this an important factor in making the British farmer competitive with his colleagues in countries of more predictable weather conditions.

ACKNOWLEDGMENT

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SUMMARY OF DISCUSSION

Mr. Hartley asked if the effect of height on the drift of aerial spray applications was more significant than that of cross wind. Dr. Ripper replied that the relative importance of height and wind to spray drift was covered by many classical papers. A maximum height of 40 in. above the crop was really necessary to reduce drift significantly. The control of droplet size was also extremely important.

Mr. Greenley asked four questions. First, were the graphs for acreage treated in 1959 (Fig. 1) based on geographical acreage or did these figures include acres that had been sprayed several times? Second, he felt that there was a great future for rotary winged aircraft: they were able to operate under high wind conditions, they were roadable and were capable of being readily maintained in the field. What were the Lecturer's views on this subject? Third, did Dr. Ripper's figures of cost per gallon carried allow for the characteristics of a small autogyro, and would it not be reasonable in this context to consider a spray capacity of 10 gallons to be an economical unit in comparison to the 38 gallons suggested by the Lecturer? Fourth, what would be the attitude of the Air Registration Board to a robot or remotely controlled aerial spraying vehicle? Dr. Ripper replied: First, that the 1959 acreage was not geographical but included areas that had been treated several times. Second, the helicopter, primarily due to its high initial cost, had been shown to be fractionally dearer than fixed-wing aircraft for normal purposes. Third, Dr. Ripper thought that the small autogyro might be a proposition only for crop spraying but not for fertiliser spreading. Fourth, an aircraft without a pilot was not an aircraft within the definition of the law. However, it must comply with the following conditions:

(*a*) The robot machine must be readily identifiable by other aircraft as such.

(*b*) The ground control must incorporate a dead man's switch when radio transmission failed.

(*c*) The machine must, of course, be ground transported from site to site, and not flown.

Mr. Cook, of World Crops, asked how the lecturer reconciled the elimination of pilot cost with robot operation, as a robot still had to be controlled. Dr. Ripper replied that, when robots were used, part of the pilot's work would be taken over by black boxes and part by the ground crew.

Mr. J. Brown, of Cambridge, asked whether the Invert Emulsions that had been tried in the U.S.A. had proved successful in Britain for weed-killing and also what was the reason for the small number of acres that had been treated in the Netherlands? The Lecturer replied that the verdict on the first question was that it was useless. The reason for the small treated acreage in the Netherlands was that, although that country was doing more to develop Agricultural Aviation than Britain, the smallness of the Dutch fields created greater drift problems than over here.

Mr. F. Clay, of B.E.A. Engineering Base, said that there were of the order of 26,000,000 undeveloped grassland acres in this country which needed a large lime-application treatment. Would this be regarded as an uneconomical progress under present day costs, and was this perhaps the reason for lack of progress in this field of activity? The Lecturer replied that hill farming was not a particularly progressive sphere of farming activity. He also thought that a limited acreage should first be developed by this means.

This type of operation would probably require large helicopters for the heavy lime dropping on this difficult terrain.

Asked how Diquat compared with sulphuric acid for haulm control, and why such low areas had been sprayed with fungicides in Britain in 1959, Dr. Ripper replied that Diquat haulm control was not as dramatic as sulphuric acid but was as good as sodium arsenate. The low application rate of fungicide had been due to the fine weather in 1959.

Wing Commander P. R. Hatfield, of Airspray (Colchester) Ltd., asked Dr. Ripper about his views on the progress of dusting and spreading equipment for helicopters. The Lecturer replied that electric static precipitation showed great potential and much work had also been done on ram-air ventures and indeed there were many U.S.A. reports on this subject. However, these particular devices were not of much use on a rotary-winged aircraft. Hence, the spinning disc distributor had been developed, which had given excellent results.

Air Commodore A. H. Wheeler, a Consultant to the Air Registration Board, humourously said that the other condition the Lecturer had omitted to mention concerning robot aerial vehicles was that, if there were less than 11 lb., they would be outside the airworthiness and A.N.D. regulations! He asked the Lecturer's opinion on the possibility of doing away with the ground marking personnel that were today common to Agricultural Aviation and consequently, by this means, reduce the operational cost. Dr. Ripper replied that the markers had been dispensed with in certain tropical applications when the pilot could rely on the ground pattern. However, the low-level operating pilot could not be bothered with this ground pattern method. Daylight substances and other readily visible means were also used for marking systems.

Mr. Caseby, of Shell Chemical Co. Ltd., asked who would pay for these Agricultural Aviation operations on marginal lands and hill lands, as he felt this field of activity was not generally an economic proposition. This was to a certain extent being borne out by the fact that the third, and possibly the fourth, Agricultural Aviation operator had given up the business during the past year due to the poor commercial situation. Dr. Ripper felt that these aerial operations were likely to be more economical in the future than they had been in the past and they could be a commercial proposition, especially if one took into account the fact that, of a £30 per acre expenditure, 50 per cent was subsidised by the Government.

Liquid Atomisation

BY

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THE PROCESS OF ATOMISATION is of primary importance in several branches of engineering, such as in the combustion of liquid fuels, in the chemical industry, in operations involving drying, evaporation, absorption, and so on, in fire-fighting and the production and dissipation of fogs and in agriculture.

In agriculture, the spraying of small drops is employed in the dissemination of insecticides, herbicides, etc., for the purpose of crop protection, and the spraying of large drops is used for overhead irrigation.

Since the advent of the atomiser, a hundred years ago, the engineer has been in advance of theory in his practice of atomisation. For lack of fundamental data he has had to rely upon laborious hit and miss experiments to obtain a design suitable to a particular requirement. Thus the atomiser has been a fruitful avenue for the inventor. Its small size and apparent simplicity has, however, deceived many into the belief that the problem is simple. Research over the last thirty years has proved this to be anything but true, and even now our knowledge is still extremely limited.

During the past fifteen years, in all branches of industry, the application of atomisers has greatly increased and new demands are continually arising. We have now to atomise and distribute, with proper control, a much greater range of chemical solutions, emulsions and dispersions. For these reasons a more precise knowledge of the spray processes is required to enable the designer to predict the performance of atomiser nozzles under a much wider range of conditions.

The larger number of dimensional variables in the atomiser, the wide variation in the liquid properties and in the hydraulics of flow, and also in the changes in the ambient surroundings of the spray, are responsible for the complexity of the phenomena associated with spraying. Although considerable research effort has been directed towards the assessment of the effect of these many variables, the difficulties encountered both theoretically and experimentally still limit the scope of investigation.

Spraying in Agriculture

Spraying in agriculture and horticulture falls under a number of different headings, each with different and characteristic atomiser requirements. There is no universal nozzle or atomiser for all purposes.

The type of duty an atomiser has to perform can, however, be classified according to the volume of flow per unit time at a particular pressure, and whether the spray has to be projected over a long or short distance.

In agriculture, it has been usual to distribute the active chemical by spraying dilute solutions through nozzles at high flow rates, even up to 1,200 gals./hr. per nozzle, in conditions which may vary widely. The type of crop, the layout of crop, the atmospheric conditions, the form of the mechanical equipment supplying the energy for distribution, may all vary from time to time and, in some cases, from minute to minute. This variability of field conditions and the need, in many cases, to ensure complete coverage of the herbage, make it necessary to use very much more solution than should theoretically be required. Spraying to "run off" usually wastes 95 per cent of the liquid and often does not completely wet the plant. The great difference in trajectory and distance of throw required by ground and tree crops adds further variation.

At the other extreme, the fact that only a few drops of growth regulating hormones are required per leaf or plant brought about the need for nozzles capable of distributing very small quantities of liquid uniformly. Thus it became necessary to atomise to small drops and distribute with great uniformity very small volumes of 1/10 to 2 gals./hr., over large areas of ground.

When spraying crops, small drops mean drift and a low dynamic catch. Pressure nozzles for small drops mean small orifice sizes and very high accuracy in production. For this purpose atomisers using gaseous energy are sometimes attractive because the liquid orifice can be large.

In crop protection practice, liquid drop sizes corresponding to the entire natural drop size spectrum are required, and the different kinds of spray have derived their names from their drop size equivalent in nature. With water drops in free fall, as in rain, the maximum possible drop size is 8-9 mm. At the other end of the scale, a suddenly applied air blast at sonic velocity realises a survival diameter of 5-7 micron, and this size is the practical minimum average size for drops produced in ordinary spraying devices.

Figure 1 shows a drop size spectrum in microns, on a log scale.

In crop protection spray applications it is not always known which is the more useful, the number of drops per unit area, or the surface area of the spray particles —or the total mass deposited.

It is clear that although something is known of the biological effect of the size of the residual particle on toxicity, little is known about the desirable drop size which should act as the carrier. But we may, perhaps, limit our ideals to three groups of mean sizes for agriculture: 1-30 micron SMD for space sprays, 40-100

The 12th Lecture to be given before the Agricultural Aviation Group of the Society—on 29th March 1961.

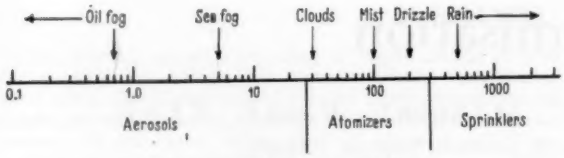


FIGURE 1. Drop size spectrum.

micron for mist blowing, and 100-300 micron for contact sprays without air assistance.

Classification of Atomisers

The engineering function of an atomiser is two-fold; first, to cause the liquid to accelerate and make it issue as a sheet and then disintegrate, and secondly, to direct the resulting particles in a controlled direction.

It is not always appreciated that the atomiser should, in the first place, produce a sheet of liquid and that it should also control—accurately—the dispersion of the drops.

In discussing atomisers it is necessary to classify them, and the most convenient classification is according to the source of energy employed. Thus they divide naturally into three basic types: those using pressure energy, centrifugal energy or gaseous energy. (Table 1.)

Many modern atomisers combine two or even all of the three sources of energy. For example, a swirl spray pressure nozzle is combined with a medium pressure air atomiser to improve the disintegration of viscous liquids; a spinning disc or cup is combined with a large volume of low pressure air to give projection velocity and further disintegration; or a pressure atomiser, working at low pressure to give large drops, is combined with low pressure air to give control of the direction of the drops. This last combination is particularly applicable to open-air spraying where small drops are not required. A medium-pressure air injection atomiser is combined with a large volume of high velocity air to give further disintegration of small drops for the purpose of producing aerosols.

There are three factors which effect the performance and drop size of a sprayer:

(*i*) the atomiser design—which determines the way in which the liquid is discharged and disrupted;

(*ii*) the liquid properties—which influence the behaviour of the disintegrating liquid sheet;

(*iii*) the spraying atmosphere—which affects the manner or mode of disintegration.

TABLE I
CLASSIFICATION OF ATOMISERS

Pressure energy used for pressure atomisers	*Centrifugal energy used for rotary atomisers*	*Gaseous energy used for twin-fluid or blast atomisers*
Fan-shaped sprays		Low pressure
Fan spray nozzles (single orifice)		0·2–2 lb./in.²
25–125 lb./in.²		Gas/liquid ratio,
Impact nozzles	Spinning cups	15–25 lb./lb.
Impinging jet nozzles	20–100 ft./sec.	
20–140 lb./in.²		
Solid surface impact nozzles		Medium pressure
Up to 400 lb./in.²	Spinning discs	2–20 lb./in.²
Deflector nozzles	100–600 ft./sec.	Gas/liquid ratio,
100 lb./in.²	Flat discs	0·2–1 lb./lb.
	Saucer-shaped discs	
Conical-shaped sprays	Radial-vaned discs	
Swirl spray nozzles	Multiple discs	
40–100 lb./in.²		
Hollow cone		
Drowned cone		High-pressure
Divergent pintle nozzles		Above 20 lb./in.²
20–1000 lb./in.²		Gas/liquid ratio,
		0·1– 5 lb./lb.

Mechanisms of Disintegration

The fundamental principle of disintegration of a liquid consists in increasing the surface area by the formation of a sheet or thread until the sheet or thread becomes unstable and disintegration occurs.

Because of surface tension, the configuration of a sheet of large surface area is unstable, and because of random disturbances it breaks up into drops which have a smaller surface area than the sheet or thread. This decrease in surface area at the instant of atomisation is quite remarkable. In many types of atomiser the total surface area of all the drops is much less than half that of the sheet from which they were formed, and with some small atomisers the reduction in area can be as much as six times. It can almost be said, therefore, that the last instant of the process of atomisation is a reversal of disintegration due to the effect of surface tension.

At the Imperial College Fluid Kinetics Laboratory we have applied many high speed photographic techniques to the discovery of some of the phenomena occurring during the disintegration of liquid sheets.

Figures 2 and 3 illustrate three methods of determining some of the qualities of a sheet of liquid. In Fig. 2 the first photograph shows a method of determining the sheet thickness by light interference. The second photograph shows that by including point source illuminators in the film, such as aluminium particles, the direction of the liquid can be determined throughout the sheet. Fig. 3 shows a method of measuring the speed of the sheet by taking two superimposed pictures, one on top of the other, at an exactly known time interval.

We learn from such photographs that the sheet can be extremely thin before disintegrating—as thin as seven micron at about one inch from the nozzle. We also learn that the streamlines in a fan sheet are straight and radial and quite unaffected by the curved liquid boundary, but the drops leave the leading edge tangentially at an angle different from that of the streamlines. Of course, if the liquid had no surface tension, the sheet would be a true sector of a circle. The force of surface tension tends to contract the sheet and bend the outward rims inwards.

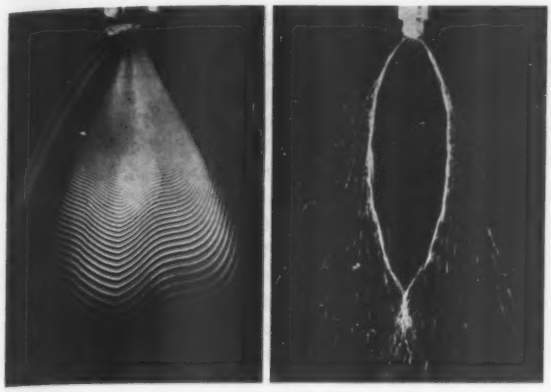


FIGURE 2.

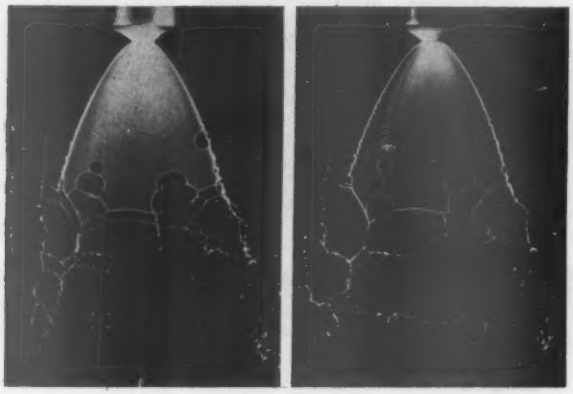


FIGURE 3.

From the photgraphs in Fig. 3 it is found that the velocity is constant throughout the sheet and there is no change in the velocity of the drops leaving it, either at the leaving edge or from the side. This indicates there is no measurable energy loss during the breaking off of ligaments and drops.

By such photographic studies we have defined four modes of disintegration. (Fig. 4).

The first mode (*a*) is rim disintegration, where threads are pulled out from the rim during the contraction of the sheet due to surface tension. Usually, this mode produces the largest drops and this method of disintegration is most prominent under conditions of low liquid velocity and high surface tension and high viscosity. The photograph in Fig. 4(*a*) is of 65 per cent glycerine/water solution.

The second mode (Fig. 4(*b*)) is what we have called "perforated sheet" disintegration, and the photograph is of water travelling at a velocity of 85 ft./sec. in a vacuum. Here the sheet becomes perforated and the liquid runs together to form threads which are unstable so that they break up into drops.

The third mode may be called "wavy sheet" disintegration (Fig. 4(*c*)) where major wave disturbances, caused by the atmosphere into which the sheet is penetrating, disintegrate the sheet by tearing away whole surfaces before the leading edge is reached.

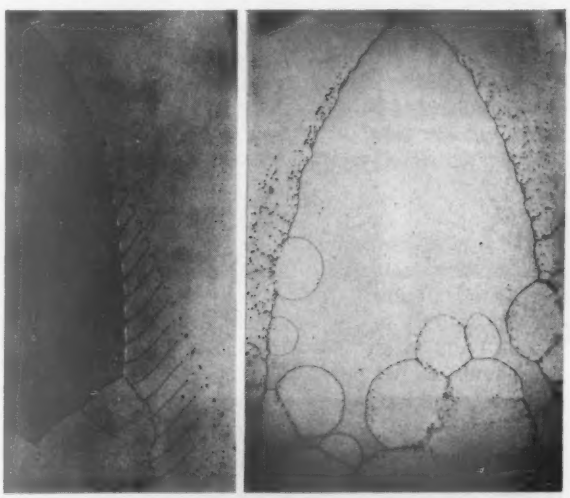
Most of the sheets produced from nozzles for practical applications have a high velocity, and turbulent flow conditions exist in the liquid orifice. Thus, liquid turbulence in the sheet is superimposed on these aerodynamic waves which arise due to the high friction in the atmosphere.

Thus the fourth mode, (Fig. 4(*d*)), may be defined as one of air impact, where the velocity of the liquid is so high that the reaction of the atmosphere tears the sheet to pieces almost before it is formed. The photograph in (*d*) is of water travelling at 350 ft./sec. in the normal atmosphere.

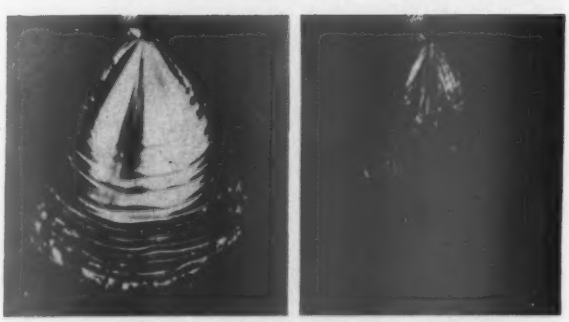
The Disintegration of Drops Travelling in a Gaseous Medium

We can say, therefore, that whatever the type of atomiser, working under practical conditions, it results in giving a velocity to the particle in the atmosphere. In all cases, therefore, this mechanism of disintegration is effective in the final stages of break up.

With drops in an air stream, two types of break-up have been observed. First, where the liquid particles are large and the unbalanced air pressure over the surface of the drop causes it to be blown into a bag. The thin film of the bag then breaks up into very small



(*a*) (*b*)



(*c*) (*d*)

FIGURE 4.

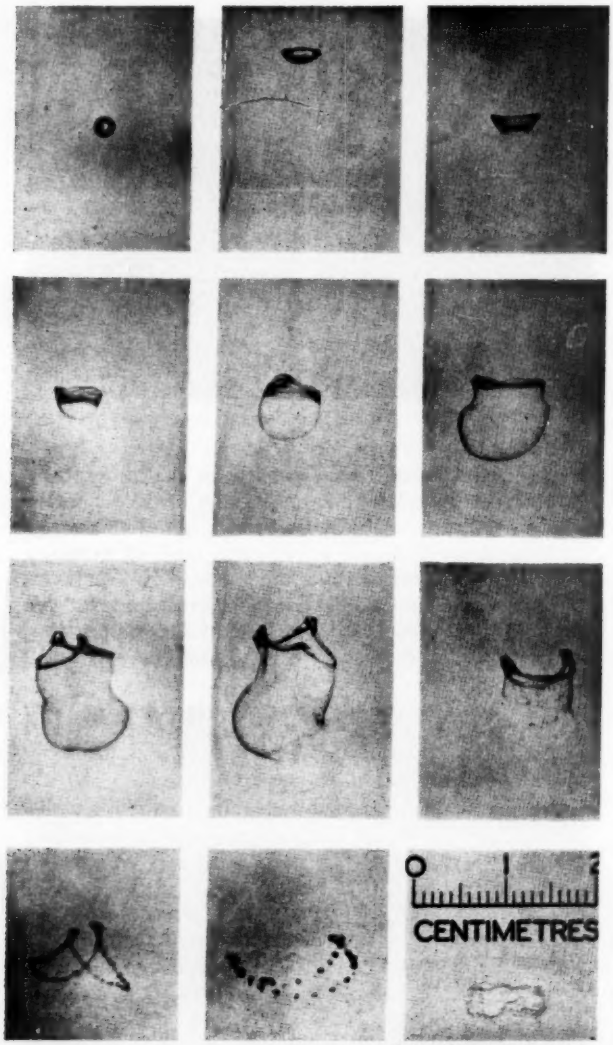


FIGURE 5.

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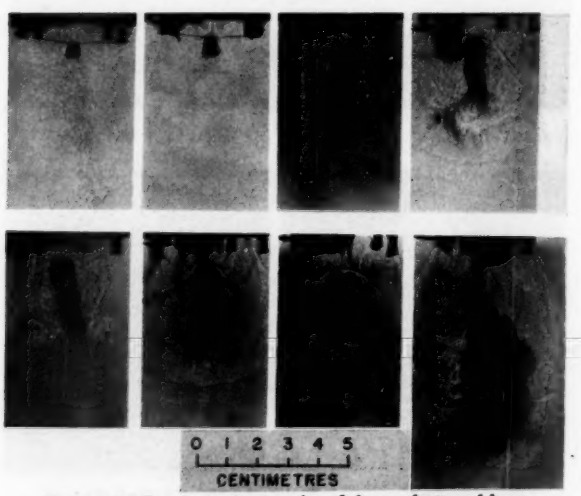


FIGURE 6. Spark shadowgraphs of drops shattered by a powerful transient air blast.

drops, and the rim of the bag breaks up into a ring of larger drops.

Figure 5 illustrates the behaviour of large drops (of from 500 to 5,000 micron diameter) in a steady air stream. This bursting bag manner of break-up only occurs, however, with low velocity particles and over a narrow range of relative air to drop velocities.

Where the air velocity is very high, the manner of break-up is different. In this case the drop becomes shaped like a saucer with its convex side facing the air blast; the edges of the saucer being blown out into a thin sheet from which the drops are formed.

Figure 6 shows a drop in a supersonic air blast.

In these experiments it is interesting to note that the drop is not shattered by the preleading shock front but by the following high velocity gas stream and, that, during the shatter, part of the drop is sufficiently coherent to offer enough obstruction to cause a shock front behind the drop cloud.

It has also been found that a drop in a steady air stream requires a higher velocity to break up than when it is suddenly placed in a transient blast. Water drops suspended in a steady air stream are extremely sensitive to sudden changes in the velocity of the air stream. The drops can be caused to break up suddenly by momentarily varying the air velocity.

When liquid drops are attached to an edge of a solid body a somewhat different behaviour results.

A high-speed ciné film of the detachment of liquid from a baffle in an air stream[1] shows that as the air speed is increased it tears the drop from the drip point producing an elongated jet which detaches (Fig. 7)[2].

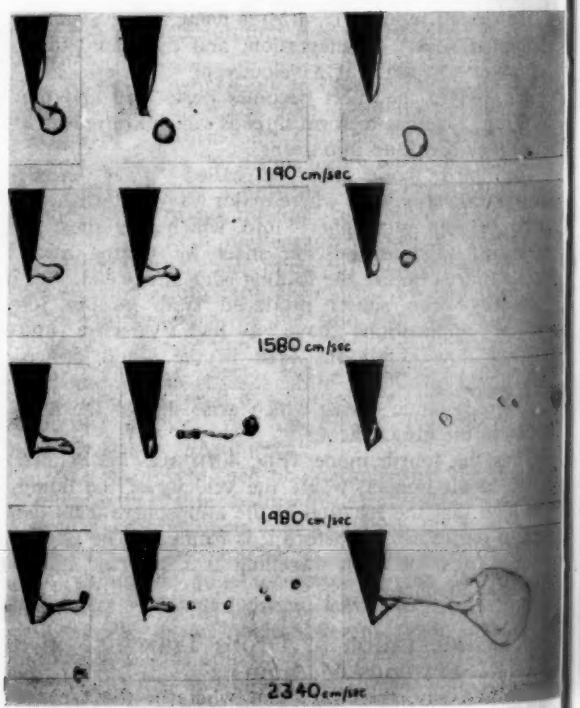


FIGURE 7.

TABLE II

Velocity V (ft./sec.)	*Critical drop diameter* μ	*Pressure Atomisers*			*Spinning Disc 6 in. Diam.*	
		Pressure corresponding to V lb./in.²	*Surface mean diameter* μ		*Speed (r.p.m.) corresponding to velocity V at rim*	*Main drop diameter* μ
			Fan	*Swirl*		
50	2650	17	309	310	1910	412
100	661	68	197	153	3820	206
150	294	153	181	135	5730	137
200	166	272		129	7640	103
300	73	612			11460	69
500	27	1700			19100	(41)
1000	7	6800			38200	(21)

At higher air velocities the process is similar to the atomisation from the edge of a spinning disc. The air stream elongates the drop into a jet or thread which then produces satellite drops. The process is continuous, drops being torn off from the main drop as fast as the liquid pours into the drip point. At high velocities the liquid may film into a bag which then breaks down in a thick rim in the manner of a free drop in an air stream.

From these studies it can be shown that there is a critical drop diameter below which drop shatter in an air stream will not occur. For water, this can be simply expressed as $V^2d = 6{\cdot}61 \times 10^6$. Where V is the velocity difference ft./sec. and d is in microns. This simple equation for water gives a critical drop size at sonic velocity of about six micron. Therefore, we would not expect drops smaller than this in any type of water atomiser.

Another way of expressing this relation is to say that for any given air velocity there is a critical drop diameter below which drop shatter will not occur.

Table 2 gives the critical drop diameters for sprays from different types of atomiser.

The table shows that at a small difference of velocity between the drop and the air at 50 ft./sec., the critical drop diameter for water is 2,650 micron. Whereas a fan spray or swirl pressure nozzle producing a drop having 50 ft./sec. velocity would give a mean drop size of about 309 micron, while, at a velocity difference of 200 ft./sec. the critical drop size is 166 micron. The fan spray producing a drop at this latter velocity would be shattering down to smaller drops by air reaction.

Liquid Properties

The general effect of liquid properties, surface tension and viscosity is well illustrated in Fig. 8. It shows four sheets of liquid travelling at the same velocity but varying in viscosity and surface tension. The top two photographs (which are of ethyl acetate and water) have equal viscosity but a three-times increase in surface tension. It is noticeable how much smaller the sheet is with the high surface tension. The lower two photographs (which are of butyl alcohol and

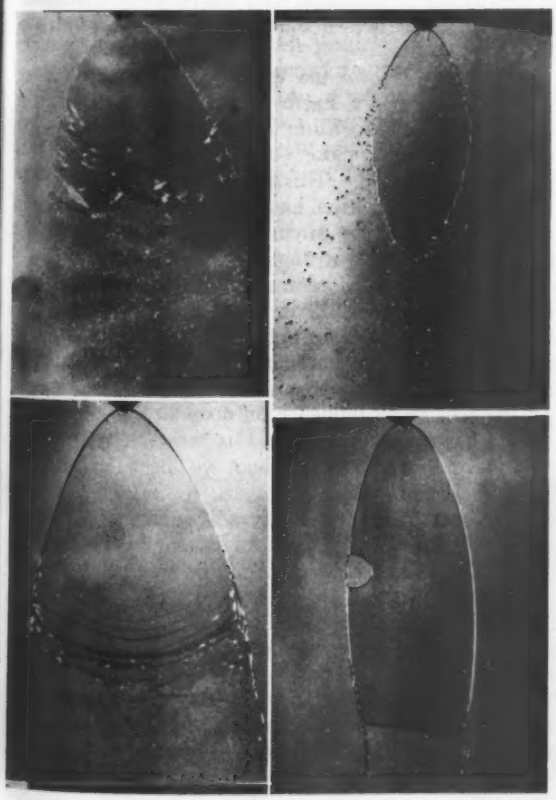
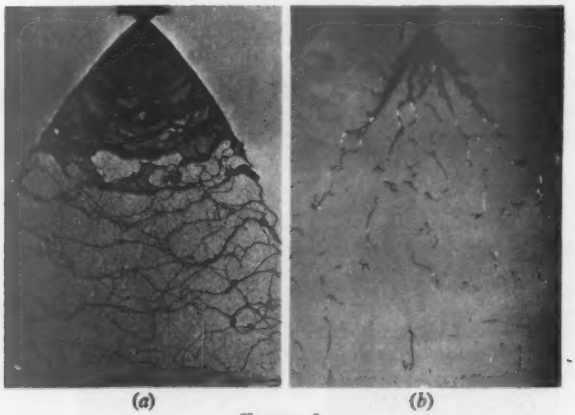


FIGURE 8.



(*a*) (*b*)

FIGURE 9.

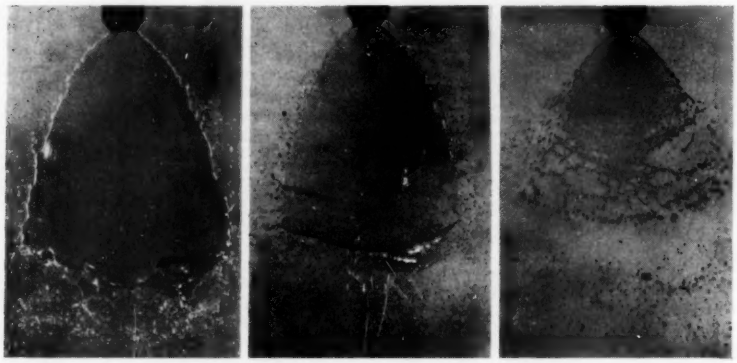


FIGURE 10.

glycerine/water) also have a ten-times increase in viscosity than the two above, but the same difference of surface tension. The effect of viscosity is to give a much larger and more placid sheet, and the effect of surface tension is still apparent in reducing or controlling the extent of the sheet.

On the whole density has little effect. But it may have much more importance when combined with very high surface tension, which comes into play in sheets of liquid metals such as mercury, sodium, aluminium and copper.

Fig. 9(*a*) shows a photograph of sodium, and here the very high surface tension contracts the sheet so quickly that threads are formed almost instantaneously.

The Effect of Additives on Disintegration

In agriculture it is unusual to use pure liquids for spraying and many mixtures have almost indefinable physical properties. It is therefore important to know what are the effects of surface active agents or spreaders; what is the effect of suspensions of powders, and what is the effect of certain chemical ingredients which may produce anomalous or non-Newtonian properties in the liquid.

With the exception of surface active agents we know little about the effect of additives which may include materials like wheat, soya bean flour, resin oil mixtures and even glues. Usually, the agricultural engineer is not very concerned about the effects of these additions on the physical properties of the spray, except as regards the mechanical convenience in handling, such as viscosity and corrosiveness.

Where liquid particles are suspended in the liquid vehicle in the form of an emulsion, or solid particles are added, it is found that the stability and the mode of disintegration of the sheet depends quite markedly upon the type of suspended particle; particularly whether the particle is wettable or unwettable.

Generally, it is found that low concentrations of small particles have no effect on the process of disintegration, even when the particles are greater in diameter than the sheet thickness. In other words, when the particles are wetted by the liquid they have no effect on the manner of disintegration. But when the particle concentration is increased to a slurry, or is unwettable, a marked difference in the method of breakdown can be observed.

Figure 10 shows the effects of adding increasing amounts of Fuller's Earth to water. At 20 per cent weight volume suspension the sheet is found to break down very much closer to the orifice through the formation of holes. This considerable change in the mode of disintegration has an influence on the drop size, the drops being larger because the sheet has not expanded so far.

With suspensions of unwettable particles, such as sulphur in water, or oil in water, the particles have a marked effect and cause perforations in the sheet.

With unwettable particles the larger the particles in suspension the earlier the sheet will perforate and the greater will be its influence on drop size.

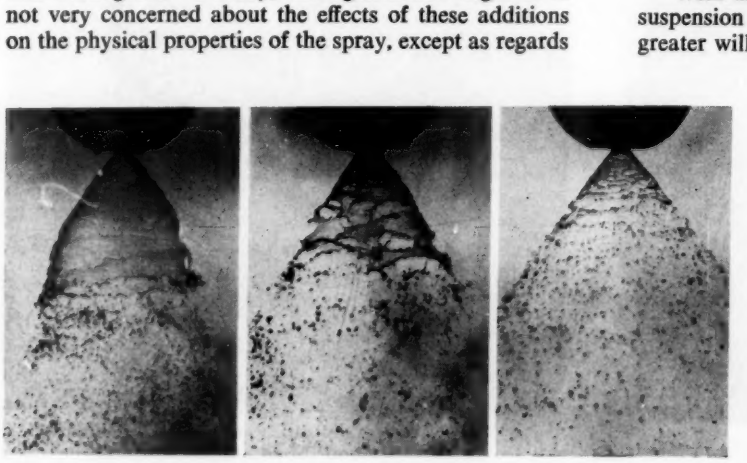


FIGURE 11.

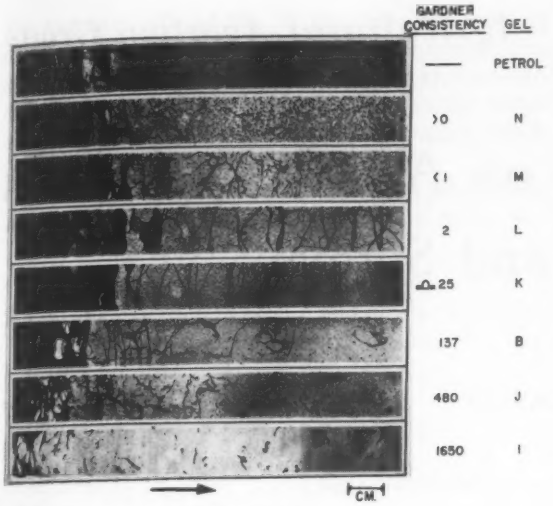


FIGURE 12.

The effect of wetting agents in aqueous mixtures is somewhat complex. First, because the sheet of liquid exists for such a very short space of time (two to three thousandths of a second) the surface active agent has little chance of affecting the surface tension. It is found that the addition of a wetting agent to pure water gives no observable change in disintegration, but when the agent is added to hard water it may precipitate some of the hardness and then it behaves in the same manner as a suspension of unwettable particles.

Figure 11 shows the effect of a wetting agent in hard water on a conical spray from a pressure nozzle. It is noticed that the sheet quickly becomes perforated and, with increase of wetting agent concentration, holes are formed almost immediately the liquid leaves the orifice.

The Effect of Visco-Elasticity

One way of controlling drift when spraying small volumes of highly concentrated insecticides or hormones should be to control the liquid properties so that no small drops are formed. This is a much more positive approach than trying to control the particle size by the design or pressure of operation of the atomiser.

The reduction of small drops or satellite drops can be accomplished by modifying the properties of the liquid vehicle so as to prevent their formation. Generally speaking, the viscous flow of liquids follows Newton's law; that is to say, the rate of flow and the rate of shear are proportional to the force or pressure applied.

The existence of non-Newtonian liquids has been known for some years, in which the viscosity of the liquid varies with the rate of shear. Only under high shear conditions is the viscosity of such liquids reduced sufficiently to allow disintegration to occur. This non-Newtonian property is sometimes referred to as visco-elasticity and, in some cases, this may be so great that the liquid appears to be a semi-solid gel, but its characteristic is that upon movement or application of shear stress it immediately becomes fluid, assuming a semi-solid state again when it becomes stationary.

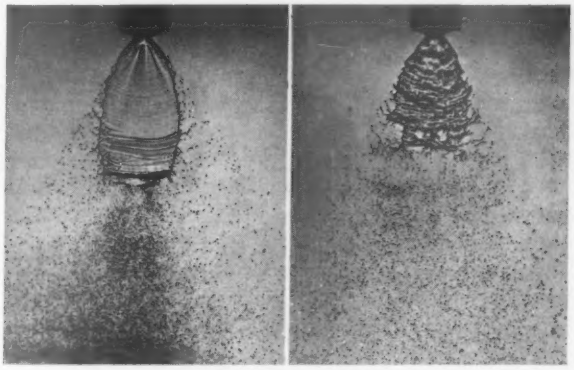


FIGURE 13.

Figure 12 shows a series of photographs of sheets having increasing visco-elastic properties. It can be seen that as visco-elasticity increases the fine droplets become threads or fibres which eventually only break up into short lengths or cylinders and no droplets are formed.

Figure 9(*b*) shows a full sheet having a small amount of visco-elasticity where threads are formed with beads or droplets on them. It appears apparent, therefore, that it may be possible in the future to control the disintegration process by introducing small amounts of visco-elasticity in the liquid.

Figure 13 illustrates the comparison in the disintegration of plain water, and water containing a small amount of gel compound. This has materially increased the drop size and removed the small satellite drops.

ACKNOWLEDGMENTS

Permission for the reproduction of illustrations is gratefully acknowledged to W. R. Lane and M.O.S. (P. & S.) for the photographs in Fig. 5. (British Crown copyright reserved, reproduced by permission of the Controller, Her Britannic Majesty's Stationery Office) and to D. M. Newitt, N. Dombrowski and F. H. Knelman for Fig. 7.

The remainder of the photographic illustrations were taken in the course of researches on atomisation in The High Speed Fluid Kinetics Laboratory, Imperial College of Science, London.

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The Farmer's Viewpoint on Aerial Application of Fertilisers and Sprays

BY

J. B. FARRANT

WHAT IS the normal practice of a reasonably good farmer in the matter of fertiliser application to both arable and grass crops? First, there is such a wide disparity between the practice of a good farmer and the rest that it can only be hoped that all will soon be brought up to the good standard. A recent survey showed that about 50 per cent of temporary grass and 70 per cent of permanent grassland in England and Wales still receive no nitrogen fertiliser.

Normal application to both temporary and permanent grassland (for light and medium soils) is three to five cwt. of a compound (12: 12: 18) plus two applications of nitrogen, or expressed as straight fertilisers:

60 lb. K_2O =1 cwt. Muriate of Potash.
50 lb. P_2O_5 =1 cwt. Triple Superphosphate.
100 lb. N. =5 cwt. Sulphate of Ammonia or Nitro Chalk.

It would be desirable to apply the K_2O and P_2O_5 during August and September in order that the plants could take up the nutrients during the period of growth and the likelihood of sufficient moisture from rainfall. The nitrogen application should be in two applications, *i.e.* 2–2½ cwt. in March and 2½ cwt. in late June or July. Heavy land requirements will be different:

30 lb. K_2O
100 lb. Nitrogen

The P_2O_5 probably in form of slag, should be applied in autumn or winter as, say, seven cwt. 18 per cent P_2O_5 slag every three years.

Cereal growers will, in these days, always use a combined fertiliser and seed drill to sow and fertilise the crop in one operation, and for winter-sown crops a spring top dressing is required in the period March-May.

The problem which has to be tackled by aerial operators is shown by an examination of the present cost to a farmer (who has a tractor and fertiliser drill) of applying fertilisers.

Consider the application of four cwt. C.C.F. (concentrated complete fertiliser) (12: 12: 18):

		£ s. d.
Total nutrients per acre	Nitrogen 48 units N. Phosphate 48 units P_2O_5 Potash 72 units K_2	
Cost of 4 cwt. at 21s 6d. per cwt. ...		4 6 0
Cost of application at 4s. 0d. per acre ...		4 0
Total cost per acre		4 10 0

Cost of application based as follows:

Depreciation and repair of tractor operated broadcaster	17 0
Tractor 8½ hours at 4s. 0d.	1 14 0
1 man 8½ hours	2 7 0
24 acres per day costing, say 4s. 0d. per day	4 18 0

If a more accurate application were needed, a plate and finger drill would be used and cost would go up to 9s. 0d. per acre made up as follows:

Depreciation and repair of tractor-operated drill	1 7 0
1 tractor 8½ hours at 4s. 0d.	1 14 0
1 man 8½ hours	2 7 0
12 acres per day costing 9s. 0d. per acre	5 8 0

Acting on the principle that the P_2O_5 and K_2O should be applied during August and September the following quantities could be applied by air to give a roughly similar number of nutrients:

	£ s. d.
Urea 1⅓ cwt.=48 units of Nitrogen ...	1 4 6
Triple Super 1 cwt.=48 units P_2O_5 ...	19 9
Pink Potash 1⅙ cwt.=70 units K_2O ...	1 3 4
	3 7 7
Cost of 3 applications by air at 16s. 0d. per acre per application, plus ground staff at 6d.	2 9 6
Total cost per acre	5 17 1

*A summary of the eighth lecture to be given before the Agricultural Aviation Group of the Society——on 28th November, 1960.

This compares with £4 10s. 0d. per acre when applying four cwt. C.C.F. in one application in the spring, thus saving £1 7s. 1d. per acre if the farmer applies with tractor and broadcaster. Many farmers would prefer autumn application of the phosphate and potash, which the foregoing method fails to do.

If the normal method of applying nitrogen to both grass and cereal crops were compared the costs would be:

	£	s.	d.
$2\frac{4}{21}$ cwt. S/Ammonia=46 units nitrogen	1	5	2
Cost of application by tractor and broadcaster at 3s. 3d. per acre (based on 30 acres per day)		3	3
Cost per acre	1	8	5
Aerial application of 1 cwt. Urea as follows:			
1 cwt. Urea at £24 10s. 0d. per ton ...	1	4	6
Cost of application plane		16	0
Filling tractor and man			6
Cost per acre	2	1	0

It could be seen therefore that for a single application of nitrogen, aerial spreading was nearly as cheap as the conventional way and certainly cheaper than using a 10 foot plate and finger fertiliser drill.

An important point to remember is that the timing of nitrogen application to cereals is critical, for instance a piece of winter-sown wheat or oats might require an extra dose to make it tiller out or to pep it up to overcome some pest or other: this out-of-the-ordinary application is difficult to programme by aerial application and therefore the farmer needs an alternative means of application, unless the contractor can guarantee this service, should it be required.

The timing of phosphate and potash application is not at all critical and generally speaking programming should be easy, *i.e.* a farmer would not mind whether application was made in August or September. This should enable the aeroplane operator to be fully occupied for a long time.

It has already been shown that it is cheaper for a farmer to apply four cwt. of a complete fetiliser than for an aeroplane to do it in three applications, and although it might be that the aeroplane could apply four cwt. in one operation, this meant using a compound fertiliser and straight fertilisers were considerably cheaper than compounds. There were distinct advantages in using concentrated straight fertilisers for, as has been shown, just over three cwt. of straight equalled four cwt. of compound in available nutrients. Of course, evenness of application is very important when applying such small quantities of concentrated fertiliser and quality of work would be looked at with an eagle eye by the farmer.

One point in favour of aerial application of fertilisers is that when a tractor and broadcaster travel over a growing crop, damage by the wheels may well reduce a crop yield by anything between three and eight per cent and obviously this could be of great importance.

I believe that the trend of lower prices for almost all farm produce will enable advanced methods of fertiliser application to make great strides and some form of contract spreading may well enable farmers to keep their heads above water.

If one considers a farmer with 200 acres of grass and crops requiring fertiliser, it could well be that by planning this type of cropping and winter food conservation together with a guaranteed reliable fertiliser supply and application contract, he could dispense with one man, thereby saving £550 in wages alone.

In the past there has not been any real thinking by farmers about evening out the peak times of labour requirement. For instance, spring planting of crops comes at the same time as spring dressing of fertilisers, and now that there is the flail harvester to make silage, thus enabling two or at the most three men to conserve winter fodder in plenty, farmers do not need that extra man who was putting on fertiliser during the spring rush of work. Again, the combine harvester and bulk handling of grain has reduced the August peak of labour requirements. Self-feeding of silage during the winter means that winter labour requirements are much reduced and farmers find that their peak is only too high during spring. A chance surely for contractors, aerial or otherwise, to step in and enable quite a sizeable economy to be achieved.

There is no doubt but that potato and sugar beet growers are already sold on aerial spraying of blight and virus control materials. They appreciate the freedom from damage to plant tops and the rapidity with which application could be made, no matter how wet the soil conditions might be.

There must be confidence that the job would be done within a reasonable time after the order has been given as, of course, time is vital. The farmer should give more thought to prevention rather than cure; this policy would help operators to produce a better service.

In the matter of aerial spraying of selective hormone weed killers and other obnoxious substances, I have nothing to say beyond the fact that aerial spraying of them should not be countenanced if this, in any way, could be of harm to other crops and animals. If one wanted aerial applications to become an accepted practice, offence must not be given to anyone, and thereby progress would be made.

Few, if any, manufacturers of fertilisers have given much thought to the production of special fertilisers more suited to aerial application. This is natural as the demand is so limited at the present time. The Government's policy towards agriculture is one of restriction unless costs are cut, and their insistence on reducing costs of unit production must be emphasised. The production of any farm crop is only achieved by the application of processes and materials as in the manufacture of, say, a car or a suit of clothes. To make a car cheaply a large

throughput is needed and so an expensive press to stamp out panels and so on is essential.

An expensive aeroplane to carry out one of the crop production processes might be the answer to cutting costs.

The weather can play a big part in delaying operations but I do not believe this difficulty cannot be overcome, provided both parties have confidence in each other.

SUMMARY OF DISCUSSION

The figure of 16s. per acre for the aerial application of Urea, Triple Superphosphate and Pink Potash was queried, other farmers stating they had found 18s. to £1 more realistic during the same period. The lecturer said this figure was based on his own experience with a private aerodrome in close proximity to the fertilised area from which a fixed-wing aircraft was operated. The area covered was 200 acres at one cwt. per acre.

Equipment was available capable of spreading five cwts. per acre from the air and it might be cheaper to spread a mixed fertiliser with one application instead of successive applications of pure concentrates. This would require special manufacture—at present considered uneconomic by fertiliser manufacturers.

Some discussion of grassland fertilisation took place and it was pointed out that a large amount of grassland was held by 100- to 50-acre small farmers. It was obviously essential for such people to co-operate if they were to utilise aircraft and to be measurably flexible in their selection of fertilisers.

The use of aircraft inevitably meant low application rates of highly concentrated fertilisers because of high operating costs per ton mile coupled with high initial capital outlay when compared with surface machinery. This led obviously to a highly accurate application rate being necessary and speakers gave evidence of strips being missed with resultant irretrievable crop loss. Good piloting, good marking and good distribution apparatus were essential and farmers should choose apparatus of established reliability in these respects.

The use of "prilled" or pelleted fertiliser was considered generally more accurate than powdered fertiliser as it was not so susceptible to vortex interference and drift. One contributor queried this as he had seen vortices and drift when prilled fertiliser was being used. It was pointed out that even with prilled fertiliser some became powdered and it was this percentage which gave a misleading impression. The lecturer emphasised his own successful experiences with the aerial application of pelleted fertiliser. The use of prilled or pelleted fertiliser gave rise to the ability to fly higher because of lack of drift and this higher flying itself offered certain advantages, the wider swath width obtained enabled a greater overlap (up to 50 per cent) of swath to be obtained and this meant greater accuracy of cover.

The weather conditions and time of day were discussed, together with methods of assessing results, and it was thought that these were factors requiring study, as a superficial examination of each could be misleading.

During discussion on grassland and increasing its utilisation, the lecturer said that only about half the temporary grassland in England receive any nitrogenous fertiliser but this matter would be more fully considered in a later lecture.

Distribution apparatus was discussed and it was alleged that much American apparatus designed for the application of powder was being used in an unsuitable manner for the spreading of pelleted and prilled forms of fertiliser; there was a need for an accurate rotary spreader in contradistinction to the venturi powder applicator. A cautionary note was that rotating discs gave variable results, although better apparatus had been designed and was available.

Research was discussed. It appeared that some doubt existed in the co-ordination of research for fertiliser application. Various fertiliser firms, of necessity, experimented to obtain optimum results but this was not the same as testing apparatus to see that the optimum results were achieved with any commercial apparatus. The Colonial Pesticides Research Unit seemed to be more concerned with droplet research.

Contracting as an economic factor was discussed and the lecturer gave his view that contracting fertiliser application would eliminate the need for one man when about 1,000 acres were involved.

During discussion it was pointed out by the lecturer that many farmers would not book for aerial application in advance—they were prone to regard it as an emergency operation required at short notice. This conservative outlook was typical of most farmers in most directions. It was emphasised on the farmer's side that aerial work would be helped by conscientious and accurate work.

Summarising the discussion the Chairman emphasised the need for improved distribution of fertiliser and asked if the Aviation Industry could help in improving distribution and minimising drift.—F. C. CLAY.

Future Developments in Agricultural Aviation

Air Commodore A. H. WHEELER, C.B.E., M.A., F.R.Ae.S.

WHEN ONE CONSIDERS future developments in Agricultural Aviation there are two questions which need explaining from the past and present and they are difficult to reconcile with one another. One is "Why did not agricultural aviation come into fairly general use 40 years ago in, say, 1920?" The other is "Why has it begun to come into general use now?"

*A lecture given before the Cambridge Branch of the Society on 15th November 1960.

In 1920 there was still a keen desire, at least stated by politicians, to increase food production: spreading things on the ground was slow and tedious—usually still by horse drawn equipment: there were available in large quantities very cheap and reasonably suitable aeroplanes ex-W.D. with large numbers of pilots seeking employment. Three such types were:

(i) The Bristol Fighter with a 275 h.p. Rolls-Royce engine, the most reliable engine of its time, which

Year	*Method of Delivery*	*Speed in Acres per hour*	*Cost in shillings per acre*
1900	Dumped by cart, spread by hand, harrowed in	¾	3s. 0d.
1919	Spreading only by hand	1	2s. 0d.
1960	Tractor spreader and trailer spinner	1½ to 3 6 to 10	10s. 0d. to 15s. 0d. 10s. 0d. to 12s. 0d.
1960	By aircraft	26 to 40	21s. 6d.

Notes: *Ground methods* in 1960 spread Nitro Chalk costing £12 per ton, containing 15 per cent Nitrogen.
Air method in 1960 spreads Urea costing £23 11s. 0d. per ton, containing 46 per cent Nitrogen.
(Cost in both cases taken after subsidy.)

FIGURE 1. Applying fertiliser—cost and speed 1900–1960

could be bought brand new for £20. In the Agricultural role it could have carried a load of some 700 lb.

(ii) The S.E.5a which was used extensively in the twenties for sky-writing—it was the same price, or cheaper than the Bristol Fighter. Perhaps both these were a little complicated and expensive to run, but:

(iii) The Avro 504K would have been eminently suitable in almost every way: they were actually being bought for about £10 each and then used (almost as bought) for joy-riding at 5/- per hop—a typical crop-spraying hop! In the later stages of its joy-riding career economically-minded operators used to put four passengers in the back, which represented a load of some 600 lb.

At the present time a suitable ex-W.D. aeroplane—the Tiger Moth—costs about £500 in similar condition. It carries no more than the Avro did and has a higher stalling speed; it has a more reliable engine, but at about £250, instead of £5 per replacement!

One must, I think, look beyond the science of aviation to find the answer to the questions.

In *Agricultural Chemistry* lies the answer very largely. There was, of course, the attitude of the average 1920 farmer who was suspicious to the point of fear of all machinery and an aeroplane flying low over his fields in those days would have stampeded all his livestock, including (probably) himself and his family!

Two major advances in agricultural chemistry have brought on—or at least hurried on—agricultural aviation. These are the discovery of selective weed killers and pest controls, and the enormous improvement in fertilisers measured in effective agent per unit weight (per cwt., say).

Although the 1920 aeroplane (for agricultural aviation) was at least comparable to the modern one in load-carrying it would have had to carry a very much greater weight to get the same result. Selective weed killers were then non-existent; one had reached about as far as lawn sand in those days!

Years	*Wheat*	*Potatoes*
1900–1909	17·4	5·9
1939–1948	18·8	7·1
1950–1954	22·5	7·9
1955–1959	26·1	7·9

Note: This is the *average* yield over good and bad farms.
(From an authority who prefers to remain anonymous it can be said: "40 per cent of farmers in U.K. are backward.")

FIGURE 2. Average yield of crops—U.K. 1900–1960

Cost of Applying Fertiliser

Figure 1 shows variations in the cost of applying fertilisers over the past 60 years. One need not worry much over the historical side represented by the first decade in this century, except so far as it may have a nostalgic appeal to some who may remember those far-off days when a farm bailiff was paid 18/- per week and worked all the daylight hours for that sum. But he worked slowly and his only mechanical aid in spreading was a horse and cart to lug it to the field and the spreading of chemical fertilisers was often done by hand and then harrowed over afterwards. There are two reasons why the accuracy can be vouched for in these 1900 costs. First, they came from my family estate accounts and second, there was no inducement in those days to exaggerate costs since income tax, then, had not been invented.

Special thanks for the latter information depicted goes to Cambridge University, The Shuttleworth College, Shell Chemicals and Pan Britannica Industries, all of whom went to considerable trouble to dig out the information.

Perhaps the surprising thing about these costs is that there seems not to be such a great difference as one might have expected to the farmers, but one must not forget *Subsidies* to-day. All through the 1920's, in fact until the shadow of war loomed large in the 1930's, little help was given to the British farmer. So one has the effect of mechanisation cheapening fertiliser application all through the between-war period and then Government subsidies cheapening it during the past 20 years.

A fair question here is "Why now make it more expensive by using aircraft—fixed-wing and helicopters?" To answer this one must look at figures again.

Average Yield of Crop

Figure 2 shows the increase in the average yield of crop since 1900. This increased yield has an important bearing on Agricultural Aviation. When crops are sparse and cheap it does not matter much if some of them are crushed and bruised with wheels. Most crops now—on *good* farms—are dense and valuable. A tractor and trailer can, on some modern crops, bruise up to 10 per cent of the crop.

There may be some astonishment at the relatively small (apparent) increase in yield shown on Fig. 2, but

FIGURE 3. Yearly utilisation—Agricultural aircraft.

I would like to draw attention to the word *Average*. From an authority who prefers to remain anonymous, "40 per cent of the farms in England today are relatively backward." In some cases the word "relatively" is unnecessary, some are just plain backward—and they drag the average down. In the case of the good ones therefore the increased yield is considerable.

Speed of Application of Fertilisers

Speed also has a bearing on the use of aircraft (*see* Fig. 1); it has always been a vital factor in all farming operations in this country, because of weather chiefly but recently because of labour costs and even labour shortage. More than ever a farmer needs to get his operations done in the shortest time—*at the right time*. It is true (probably) that the weather factor essentially remains the same in spite of some farmers' assurances that each succeeding year is "the worst he'd ever known!" But labour will not get cheaper and on that account it will never be advisable to carry a large staff just to deal with intermittent, but inevitably recurring, crises.

Thus if a farming operation is worth doing, it is worth doing quickly—it will probably rain tomorrow!

It is for this reason that aviation is invading the agricultural world and in spite of setbacks and difficulties it is my opinion that it has come to stay and come to take over many operations previously done from the surface. If that is so, one must look ahead and see how aviation in agriculture can be made more useful and economical.

Yearly Utilisation of Agricultural Aircraft

Perhaps the first thing to consider is how to make the agricultural aircraft pay. After two relatively unrewarding seasons this problem is uppermost in many operators' minds. One obvious factor is utilisation. On Fig. 3, various methods of filling in the "unforgiving" moments are shown. Top dressing or fertilisation, it will be seen, could fill in nearly nine months of the year: spraying could fill in nearly five, perhaps more. Theoretically the operator should be well placed but spraying is not always *needed* and top-dressing is not always *done* from the air. What the operator wants is a certain contract for a definite period at a definite time *every* year. Not a sort of "fire brigade" demand: "I'll have you if (and when) I want you." Then he could plan his operation with some certainty of a steady profit. The utilisation need not so much be high as certain. The combine harvester utilisation (*see* Fig. 3) is restricted to about eight weeks' operation in the year and it is a very expensive piece of equipment. It has come to be accepted that one must have it even with its high cost and restricted utilisation. I never heard of a farmer, or farm contractor, trying to adapt and transport his harvester, say, to the Bahamas in the off-season to pick coconuts! ! !

One just accepts the economics of it *but* the utilisation when it does come round is certain. That is what the aircraft operator wants but *does not* get.

One can hardly expect it in many forms of spraying—bugs and pests (alas for the operator—good luck to the farmer!) do not thrive every year. One can, however, perhaps in the very near future foresee a regular requirement in spreading not only because one does it fast, not only because one does not damage the crop but, and this is significant, because the trend is all towards one being able to do it economically—economically because one may have a regular demand for it. The thing is a *virtuous* circle.

The obvious way of increasing utilisation is by extending the season—this is done geographically by extending the operating area—there is cotton in the Sudan, there are bananas in other parts, and so on, and so on, but I will not dilate on this.

A sideline in utilisation which is worth mentioning here is that the operator would be well-advised to search earnestly for alternative employment in the off-seasons. Just for interest, and perhaps inspiration, here are a few examples of operations which have been done.

FIGURE 4. Showing negligible difference between drilled and undrilled (broadcast) wheat.

It is not generally accepted practice to throw, say, corn on the ground and not bother to drill or harrow it in, in fact, some eminent authorities told me that it would not grow that way or at least—this time more accurately—that the yield would be lower, chiefly because of depredations by birds. I made an actual check test to find out what really happened. The strip in the middle was just thrown down and left; the rest was raked in. To simulate making the seed unpalatable for birds—an operation which may soon be possible—I pegged over the uncovered seed a length of wire netting. Photographs of the result showed that there is only a small difference apparent in the crop: in fact what difference there is is probably due to the fact that the wire mesh was not raised sufficiently high off the ground and the birds found it a convenient perch, in some places, to stand on and peck through the mesh. Next year we will try to make the experiment more accurate.

But the important thing about this experiment is not so much that it may be possible in the future, and in very wet seasons, to sow at the right time from the air rather than to wait till the weather permits a very late sowing, but to suggest that there may be many such operations in farming which people think cannot be done from the air but which can be done, and in many cases done better.

I am not, at this stage in the evolution of the art of Agricultural Aviation, suggesting that one should start considering lifting potatoes by helicopter!

Another example of the sort of allied operation which can be done by agricultural aeroplanes in the off-season was the use to which the Lancashire Aircraft Company put its Prospector—spraying waste oil which pollutes our shores all too frequently with an agent which makes it sink or disperse. Again, Helicopter Services Bell helicopter has been used to lug concrete to build an island 500 yards off-shore in the Bristol Channel. There are many such types of operations which can best be done by helicopters but the people who have to do them do not realise it.

To return to farming, and cheapening the aviation service to farmers, reliability, speed and general efficiency are essential if farmers are to keep up a regular demand. Economy is all important. What other means besides diversification to give better utilisation are there for improving economy and therefore *cheapening* the service?

The aircraft must be cheap, reliable and effective, and perhaps here one touches on the whole reason for the worries in agricultural aviation today. Has it, in fact, come too soon? Was it, in fact, brought on a little ahead of its true economical evolution because a large number of cheap ex-Service aircraft suddenly became available? This refers chiefly to this country, not to others where only aircraft can do the job and where, at almost any price, it is worth doing.

Apart from the cost of the aircraft, the cost of operating it is high even though in many cases the pilot is called upon to carry a far greater responsibility and do a far heavier job than normal beings should be asked to stand. Then there is all the ground organisation. One cannot avoid the necessity for getting the right stuff to the right field at the right time, but does one really have to employ two able-bodied and highly paid men to act as markers? Various means have been tried to cut out this burden of cost but none has yet proved entirely satisfactory. Perhaps it could be done though? If it were, almost overnight the cost of spreading by air would drop to, or below, the cost of surface spreading.

Could one have a better type of aircraft? I will not enter the argument as to fixed or rotary wing—I sit on both sides of the fence!—and you all know the arguments both ways. One could have an aircraft which carried a greater weight and flew slowly more safely and used less fuel and was more reliable and less tiring, but all these points are hardly comparable with the "marker" significance and, if one is not careful, a better aircraft carrying more will involve the need for four markers instead of two!

Suggestions have been made for a pilotless robot machine and this may have great possibilities but it will need careful planning or one will merely take the pilot out of a simple machine and have him sitting stationary in a much more complicated one, flying (remotely) a still more expensive piece of equipment which still needs markers who, in turn, will each have to carry little (expensive!) beacons to help guide the thoughtless robot!

If one were rash enough to predict a future I think we may, within 15 years, see an economical robot working; but between now and then I see—in this order—the following developments:

1. Streamlining of the present organisation enabling some of the administrative load to be taken off the pilot.
2. Elimination of the markers, by some scientific means—many are theoretically possible.
3. Planning farm cropping—even between farms—to allow more efficient flying.
4. Improved aircraft.
5. A possible robot working in most weather conditions, day or night.

Developments 1, 2 and 3 will bring the cost of air application down to a level when even backward farmers—and (remember the anonymous Authority who would not like to be quoted) 40 per cent of the farmers in this country are backward—to repeat, when even backward farmers will demand air deliveries. This demand will pave the way—with silver if not gold—for building better aircraft finally, perhaps, producing the robot, but he is in my opinion, some way off yet.

The Royal Aeronautical Society
The First Fifty Years

BY

J. LAURENCE PRITCHARD, C.B.E., Hon.F.R.Ae.S., Hon.F.I.A.S.

1876-1877

The first paper read at the 1876 meeting was by D. S. Brown, his fifth paper to the Society, entitled " The Advantages of employing power for aerial propulsion in an intermittent manner, and on the soaring of birds."

Brown was silent on the advantages of intermittent application of power for flight, and was not much impressed by Sir George Cayley's ideas about birds soaring in upward currents of air reflected from cliffs, hills, and so on. But he spoke with obvious knowledge of the effects of increased size on a weight-strength ratio in the light of the cube/square law.

James Armour, whose paper, " Wings for Men," filled fifty pages of small type in the 1873 *Annual Report*, presented a further paper on the subject, read this time by Brearey in the absence of the author, entitled " Air Compression under Wingplanes." James Armour was a good engineer, and had to confess that though he argued on general principles about the supporting forces of an aeroplane in full flight, there were many unknown parameters.

" Experimental data are yet needed to determine the rate at which the expansive pressure of the cushion diffuses itself with displacing force through the bulk of free air beneath and, likewise the limit to which, with a given velocity and angle of inclination, the narrowing of the wing plane may be carried without loss of effect."

Armour argued that the resistance of a moving wing depended upon the area multiplied by the distance flown in unit time. He discussed afresh the rotating series of planes, as those of a paddle wheel, each blade being curved in a wave form.

Thomas Moy read a paper with the unusual title, " Reply to some remarks in the *Quarterly Review* for 1875."

The *Quarterly* had attacked the heavier-than-air school of flying, and said, what could not be denied, " At all events a dirigible balloon is a thing actually in existence; a flying machine is, at present, only an idea."

Moy was not overawed by the *Quarterly*, powerful as it was.

" When I had read these remarks in such a work as the *Quarterly*," he said, " I drew a long breath and rubbed my eyes with surprise and astonishment, as I considered that every writer of ability had educated himself beyond this; but, as I find that such opinions are only too common, I will trespass upon your time for a little while in order to put the matter in a clearer and more correct light."

Moy was not content with tearing the balloon to shreds.

" I consider that I have some right to speak thus, having spent a large amount of money and time in arriving at the highly favourable result which I obtained twelve months ago, when a 3-horse engine lifted 120 lb. dead weight, in the presence of some of the most distinguished members of the Society."

Moy was destined to spend much more money without solving the problem, and to leave nothing but a memory of a great aviation pioneer. Eight years later he lectured before the Balloon Society and finished with the words, " We have a hundred years of balloons and it is quite time that some advance should be made, leaving drifting bladders behind."

Frederick Artingstall, a Manchester experimenter, although not a member of the Society, had, over the years, sent a number of communications to it which were read by Breary at the Annual Meetings. The first appeared in the *Annual Report* for 1866, and the last in the 1876 *Report*. In the latter he discussed the belief that the resistance of a body passing through the air varies as the square of its speed. In this short note he drew attention to the importance of the long narrow wing—the wing of high aspect ratio—for getting the best lift and least resistance.

Alphonse Pénaud's paper on "The Power Developed by Birds," translated by T. J. Bennett, was indicative of the keen observations of its author. His death at the early age of thirty was a tragedy, for he was showing a firm grasp of the essential difficulties which must be clearly understood to solve the general problem of flight.

" Birds require in certain circumstances a superabundance of strength, and flying machines that may be considered in the future," he declared, " will also require, though in a less manner, a store of power upon which they can fall back in an emergency; great power will be wanted to start from the ground."

Pénaud was specially interested in the power required for take-off and from his observations that, momentarily, birds are capable of a force corresponding at least

For the Peacock, one horse power for every 66 lb. weight.

For the Pigeon, one horse power for every 57 lb. weight.

For the Sparrow, one horse power for every 48½ lb. weight.

For the Sea-pie, one horse power for every 26 lb. weight.

Pénaud pointed out that there were no engines weighing less than 66 lb. per horse-power, but added, " Allow me, however, to express my conviction that, in the future more or less distant, science will create a light motor that will enable us to solve the problem of aviation."

The second paper, translated by T. J. Bennett, and published in the *Annual Report*, was called "Laws relating to planes gliding in the Air." This paper discussed the possible formula for pressure on planes in an air stream, in the light of experience.

This year saw Brearey's sixtieth birthday. He was showing as much energy as when the Society had been founded ten years previously. More, in fact, for he had begun to make model aeroplanes and gliders, for demonstrating at lectures.

He proposed to the Council that an Aeronautical Club should be formed, to meet once a month to enable its members to discuss informally their ideas and experiments. Brearey suggested that only those who were members of the Society should be eligible to join, that an annual subscription should be charged, and that the

members should dine together before they began their informal discussions. The Council agreed to contribute £5 a year towards the expenses of the Club.

Meetings were held monthly from May to October in London. The membership never exceeded twenty. No statements were ever issued about the Club's activities. James Glaisher, at one of the General Meetings of the Society drew the attention of other members to it, saying that it met " in the most effective of all ways of doing good work, socially and heartily, for the intercourse of thoughts." Among the members of the Club were Major Baden-Powell and E. P. Frost, both of whom became Presidents of the Society in later years; Alexander, member of Council and father of Patrick Alexander who became such a generous patron of the Society in its struggling days of the twentieth century; Thomas Moy, the ever faithful believer in heavier-than-air flight; and H. Middleton, lecturer at St. John's College, Cambridge, in mathematics.

Baden-Powell, in his book, " Ballooning as a Sport," wrote about the Club, " Some half a dozen members used to meet of an evening at a room in Conduit Street to discuss matters in an unconventional way. We had several interesting talks, but this sort of thing soon palled on me. We had no funds to do anything more, and talking, if cheap, becomes nasty after a time."

The plain fact is that each member had his own axe to grind. Baden-Powell joined the Club in 1880 and said it served some useful purpose, if only to let off a little aeronautical steam. Hints of the atmosphere which prevailed at times appear in some of Brearey's letters and in those of the Club members. In 1885 Brearey wrote to one of his correspondents, " You ask me for the names of about twenty men who are determined to make a success of Aerial Navigation. I thought at one time to gather together into a private room a few such, and I hired a place of meeting for once a month in connection with the Society. It was considered that if six attended it was a good meeting. It collapsed for want of support."

Thomas Moy was probably one of the most difficult of the Club members, although Brearey must have run him a very good second. In 1903, when Moy was in his eighty-second year and had fallen on evil times, he wrote to E. S. Bruce, the Honorary Secretary of the Society, after explaining that he had no income.

" You are probably not aware that in 1874-75 I spent £1,500 of my own money in experiments in aerial navigation. Also that from 1868 to 1879 I was the assistant adviser of Brearey. When the Club dinner was given by Mr. Brearey at the Crystal palace, Mr. Glaisher being in the Chair, Mr. Brearey stated that the Society must have collapsed several times if he had not had Mr. Moy to fall back upon for something worth bringing before the meetings."

Both Moy and Brearey were certain they had discovered the secret of flight and both were convinced that it was only lack of funds which prevented them from being hailed by the world as such.

By the end of 1876 Brearey had developed his models and acquired aeronautical jargon and knowledge to such an extent that he engaged to undertake an extensive lecture tour. He lectured to a great variety of audiences, from the Young Men's Christian Association (who prayed for him before he began) to the Mechanics' Institutes, the Literary and Philosophical Societies, and the British Association. His lectures were received with a very great variety of outlook in consequence.

In December he lectured at Ryde in the Isle of Wight to the Y.M.C.A.

There is little doubt that the demonstration of flying models by Brearey appealed more than his ponderous (and often prejudiced) explanations of flight. In February 1877 he lectured at Plymouth, Liskeard and Truro. The *Royal Cornwall Gazette* reported: " I cannot give you a word of the lecture, it was so learned and so crammed with figures and ratios and inverse proportions and all the rest of it; but the models of flying machines were interesting. They flew about the room like birds, in a manner marvellous to behold, and even fluttered when they descended upon the platform. Then there were little coloured vertical screws which went flying and twisting and dancing against the ceiling, much after the manner of a daddy-long-legs, and quite as graceful. Finally there were bats. I never did like bats and to see the way they swooped down on the heads of the assembly was horribly natural."

It is a misfortune, from a historical point of view, that none of Brearey's models appear to have survived. In a letter to John Stringfellow, dated 29th December 1877, he wrote of his models, " There are more than 30, and make a good show, from wings of 6 inches up to 12½ feet from tip to tip. I mounted the two crows' wings which you sent me, and I could not get it to fly a bit. I then ascertained that a crow weighs about 17 oz. I added a half pound to the weight and it flew 16 feet."

The membership at the end of 1876 was 102. At the May meeting of Council Brearey reported a balance of £32 18s. 11d. after payment of all bills.

The Annual General Meeting held on 13th June 1877 was not a very good one. It had been called together by Brearey before he had any reasonably good paper to be read, and he himself had to fill the breach with the lecture which he had been giving so successfully in various parts of the country. One must really give him full marks for his energy and enthusiasm. He was in his sixty-second year, and travelling in those days was hardly comfortable or speedy. Moreover he had to pack and unpack at often short periods the many models he showed, and re-adjust them each time.

On 27th January 1877 he had written to John Stringfellow a letter which throws a vivid light on his lecturing activities.

" The time is coming when I must start on my tour. My first is Liskeard on Tuesday 6th February. If you and your wife are well enough, and other matters agreeable, I should like to come to you on Friday the 2nd February and leave you for Liskeard on Tuesday morning. Then I lecture at Plymouth, Wednesday, Redruth, Friday, Penzance, Monday, Leeds, Wednesday, Keighley, Saturday. In the meantime, every moment is occupied, so farewell."

His moments were, indeed, fully occupied, and few lecturers could have kept up the pace as Brearey did. These lectures were a good advertisement for the Society, although the subject did not always draw a good audience.

The *Penzance Tidings* reported the lecture " excited much interest " and the *Royal Cornwall Gazette*, of the lecture at Truro, of the flying models, reported " they flew about the room like birds, in a manner marvellous to behold," but the *Tunbridge Wells Gazette* declared, "Notwithstanding the great interest attached to the subject of flight it would seem that Tunbridge Wells does not delight in scientific lectures . . . The lecturer came

with good credentials but the subject failed to draw; this fact, however, did not prevent those present from being highly interested . . . At the second lecture on Thursday evening the audience was smaller than before." Even Brearey, when replying to a vote of thanks, was driven to declare that a scientific lecture did not seem to draw in Tunbridge Wells!

But listen to the report of the *Falkirk Herald and Linlithgow Journal* for 22nd November 1877.

" To those interested in aeronautical subjects, the lecture could not be otherwise than highly interesting, but to the majority of those who composed the audience last night, which was a large one, much of the necessarily scientific lecture proved unpalatable, and there was a good deal of restlessness and fidgeting in consequence. The lecture was illustrated by numerous experiments demonstrating various forms of flight, and the hovering of the various 'birds' above the heads of the audience and their final alighting thereon caused no little amusement. It is a pity so much was lost to those of the listeners who were interested in the subject by the frequent interruptions of others who were not interested. These interruptions were frequent towards the close, and much of the subject matter was lost."

Brearey lectured to the Society at this Annual Meeting, under the title " The Problem of Flight." It was the same lecture he had been giving in the provinces and at the London Institution.

" I almost think it was the first public lecture upon such a subject delivered before a London audience," he declared. His lecture not only gave a general picture of the aeronautical outlook of the time, but revealed, too, the standing which Brearey had in the eyes of the members of the Society.

The Chair was taken by James Glaisher, who, when the lecture and discussion were over, declared: " I need now only express the pleasure we all feel in seeing these models. Mr. Brearey has been working at them for a long time. The beautiful action—the bird-like motion—of these models becomes very interesting when we consider that it is produced by mechanism, and I believe that by following up these experiments, even if the problem of flight be not solved, our knowledge upon many points will nevertheless be greatly increased. With these remarks I will ask you to give the warmest thanks you can to Mr. Brearey, because it is to his energy and zeal, ever since the Society was established, that we owe its existence now. He frequently calls upon me, and is always occupied with the investigation of some original and undecided point in our subject. It is to him that I owe the honour and pleasure of being here this evening. He came to me this morning and would not take 'No.' It is a great thing when a man will not take ' No '."

Brearey was much moved by this unexpected tribute, for unexpected it certainly was. " I am very much obliged to you for the kind terms in which you have spoken of me," he said. " It is the first time in twelve years I have received a vote of thanks, and I appreciate it the more."

" It is a great thing when a man will not take ' No '," declared Glaisher, himself one of those men. No greater tribute or advice could be given to the Secretary, Honorary or otherwise, of any organised Society, for upon him, in the final analysis, must rest the success or failure of the Society.

In 1875 Sir George Nares had led an Arctic Expedition and Brearey, during his lectures in the country, had been asked time and time again why balloons had not been used. He took the opportunity at the Annual General Meeting, to start a discussion on the subject, declaring that he did not want to express an opinion one way or the other. Nevertheless he emphasised the disadvantages more than the advantages, while at the same time declaring that a balloon ought to have been considered for observations at least. Although Brearey was against balloons he did not hesitate to blame those who believed in them for not making use of them when opportunity afforded.

There was considerable discussion on the difficulties of generating hydrogen in the intense cold of the Arctic and the cumbersome apparatus which must be carried.

Opinion, however, was so divided at the Meeting that no firm ideas were put forward.

Thomas Moy, who followed the discussion with a paper on " The Choice of Means for Experimenting in Aeronautics," had an opportunity to let fly at balloons.

" Bear in mind that you can never make it anything else than a drifting machine. You may try to make it a model of the planet Saturn; you may put to it any amount of sails or other gimcracks; but it will remain nothing else than a drifting machine, able only to ascend, descend, and drift with the wind."

He did not neglect a diatribe on the dirigible after his outburst on the balloon.

" Here you have a little scope for a very gentle propulsion in calm air, but it is only a little less a drifting machine than the globe. You might carry up two aeronauts and a screw propeller, and do a little feeble work, but it is useless to expect much more from this form.

R. C. Jay, an active member of the Aeronautical Club as well as of the Society, showed a model of a new type of airscrew he had produced to give a better thrust than any yet tried. It was based on the action of a bird's wing in flapping flight. A full description, with an illustration of Jay's model, was not published in the *Annual Report* until 1879, with a statement that it had been omitted from the 1877 *Report* for want of space.

In the twelfth *Annual Report* Thomas Walker's " Treatise on the Art of Flying," first published in 1810, was reprinted.

In the Concluding Remarks it was noted, " This essay, considering the time when it was printed, is remarkable, inasmuch as the author ignores the balloon as an available means of flight, or of traversing the air in any direction at will."

It was in these Concluding Remarks that Brearey wrote, " When the subject of Aerial Navigation is only mentioned in the presence of ordinary persons, it is received as though the believers in its possibility are fit subjects for lunatic asylums."

Nowadays it is fully—almost officially—recognised that though one does not have to be mad to succeed in aviation, it is certainly one of the assets.

No list of Members was published at the end of 1877.

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TECHNICAL NOTES

A Note on the Choice of Co-ordinate Functions for the Rayleigh-Ritz Method

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THE Rayleigh-Ritz method for approximate solution of equilibrium or stability problems in elasticity is based on the theorem of the minimum of the total potential. Hence the assumed displacements have to satisfy only the geometrical boundary conditions of the problem in order to be admissible. The displacements are expressed as a series of suitable chosen functions, called co-ordinate functions, multiplied by parameters which are determined by the minimisation procedure of the method. Except for the essential requirement that these co-ordinate functions have to satisfy the geometrical boundary conditions of the problem, no general rule for their choice can be given, and experience and physical considerations have to be relied upon.

Some authors (*see* for example Refs. 1-3) suggest that the choice of co-ordinate functions which satisfy also the natural (or equilibrium) boundary conditions will usually yield better results in practical problems. On accepting this advice, one could conclude that for the same number of free parameters (to be determined by the Rayleigh-Ritz method), one would obtain a better or *at least not worse* approximation by using co-ordinate functions which satisfy also the natural boundary conditions of the problem. However, this need not always be so, as will be shown by an example.

The discussion is now limited to stability problems where the Rayleigh-Ritz solutions are upper bounds, so that the relative accuracy can be gauged also without knowledge of the exact solution.

First, a simple supported column of constant bending rigidity EI is considered (Fig. 1(*a*)). The geometrical boundary conditions are here

$$y=0 \text{ at } x=\pm b \quad . \quad . \quad . \quad (1)$$

and the natural (or equilibrium) boundary conditions are

$$y''=0 \text{ at } x=\pm b \quad . \quad . \quad . \quad (2)$$

The co-ordinate functions compared are all polynomials. For one free parameter, the lowest admissible polynomial is

$$y=A\,(x^2-b^2) \quad . \quad . \quad . \quad (3)$$

which satisfies only the geometric boundary conditions, Eq. (1). The equilibrium boundary conditions, Eq. (2), can be easily satisfied by raising the power of the polynomial to

$$y=A\,(x^2-b^2)^3 \quad . \quad . \quad . \quad (4)$$

But Eq. (4) is not the lowest power polynomial satisfying all the boundary conditions. That polynomial is

$$y=A\,(x^2-b^2)\,(x^2-5b^2) \quad . \quad . \quad . \quad . \quad . \quad (5)$$

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TABLE I

Co-ordinate functions	$P_{cr}b^2/EI$	
	1 Parameter	2 Parameters
Lowest polynomial satisfying only geometric boundary conditions, Eqs. (3) and (6)	3·0000	2·4687
Higher power polynomial satisfying all boundary conditions, Eqs. (4) and (7)	11·0000	10·5971
Lowest polynomial satisfying all boundary conditions, Eqs. (5) and (8)	2·4706	2·4674
Exact solution	2·4674	

For two free parameters Eqs. (3) - (5) extend to

$$y=(x^2-b^2)\,(A+Bx^2) \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$y=(x^2-b^2)^3\,(A+Bx^2) \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$y=(x^2-b^2)\,[A\,(x^2-5b^2)+B\,(x^4+b^2x^2-14b^4)] \quad (8)$$

respectively.

The critical loads, or rather $\left(\frac{P_{cr}b^2}{EI}\right)$, for the above assumed displacements are given in Table I.

The results for this example show, that if care is taken to use always the lowest power polynomial, the co-ordinate functions satisfying also the equilibrium boundary conditions yield a better approximation. This example therefore supports the recommendation for the choice of co-ordinate function given in Refs. 1-3 and in other books. But it is easy to find examples disproving it. In passing, it is worth noting the importance of starting the assumed displacement function with the lowest order admissible function of the family.

As a contradictory example, a simple supported column of linearly varying bending stiffness $EI=(EI)_0[1\cdot01\mp(x/b)]$

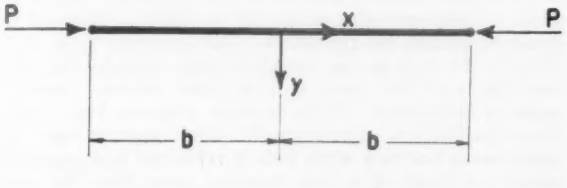

FIGURE 1(*a*).

is considered, Fig. 1(*b*). Again polynomials are compared, but here only the lowest order ones, Eqs. (3), (5), (6) and (8). The critical loads are given in Table II.

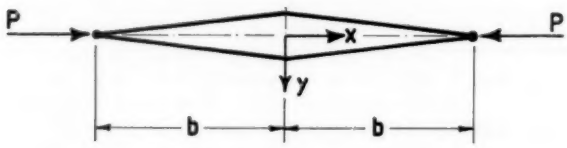

FIGURE 1(*b*). (b) $EI=(EI)_0\left(1.01\mp\frac{x}{b}\right)$

The results of Table II show clearly that a much better approximation is obtained, for the same number of free parameters, if only the geometric boundary conditions are satisfied. The physical reason for these results is the unimportance of the shape of deflection function near the ends in the column of Fig. 1(*b*), due to the low rigidity there.

In conclusion, it can be stated, that although in many cases the use of co-ordinate functions which satisfy also the natural boundary conditions yields a better approximation, there is no certainty that the results may not be worse than that obtained with co-ordinate functions satisfying only the geometric boundary conditions.

TABLE II

Co-ordinate functions	$P_{cr}b^2/(EI)_0$	
	1 Parameter	2 Parameters
Lowest polynomial satisfying only geometric boundary conditions, Eqs. (3) and (6)	1·530	1·489
Lowest polynomial satisfying all boundary conditions Eqs. (5) and (8)	1·706	1·511

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The Pressure Registered by a Very Small Static Hole

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INTRODUCTION

Static pressure in a moving fluid is usually measured by means of a static hole either in a probe or on the wall of a duct. Such a hole creates a disturbance in the flow and thus has some error associated with it. The determination of the magnitude of this error has been attempted by several investigators and the procedure adopted in each case has been as follows:

The pressure in a region of sensibly constant static pressure was registered using holes of various diameter and a curve of pressure versus hole size plotted. The true static pressure was then obtained by extrapolating this curve to zero hole size, and the errors for the various holes were found. This procedure involves the assumption that, as the hole size tends to zero, the pressure registered tends to the true value. It is usually argued that this must be so because the disturbance caused by the static hole is progressively reduced as the hole size is reduced. Obviously, the validity, or otherwise, of the argument is of fundamental importance in the estimation of static hole error, and a somewhat more rigorous justification of the use of the extrapolation procedure is attempted in what follows.

ARGUMENTS CONCERNING THE FLOW PAST A VERY SMALL HOLE

The hole to be considered is taken to be situated on some surface which is parallel to the direction of the main flow, so that only the transverse or static component of pressure should be registered. The presence of a hole disturbs the flow in the boundary layer close to the wall, with the result that some error in static pressure measurement is introduced. There is some evidence based upon flow visualisation experiments[1] which suggests that the disturbance due to a static hole is restricted to a region of about one tenth of a hole diameter away from the wall. As the hole size is reduced, the extent of the region in which its influence is felt is also reduced. Thus, even when the main flow is turbulent, there will be a particular small hole size corresponding to the situation that the hole disturbance is only felt in a region of creeping flow, *i.e.* a part of the boundary layer in which inertia effects are completely dominated by viscous effects. The flow past such a hole can be considered as a creeping flow bounded by a moving surface corresponding to an undisturbed streamline in the boundary layer (*see* Fig. 1).

The motion of the fluid is such that the flow is governed by equations which are linear (*i.e.* the continuity equation and the reduced Navier Stokes equations) and hence, if the direction of flow is reversed, the pattern remains unchanged. Thus if the physical boundary shape is symmetrical about the plane *YY'*, it follows that the flow pattern must also be symmetrical about *YY'*. This being so, there can be no net force in the *y*-direction due to

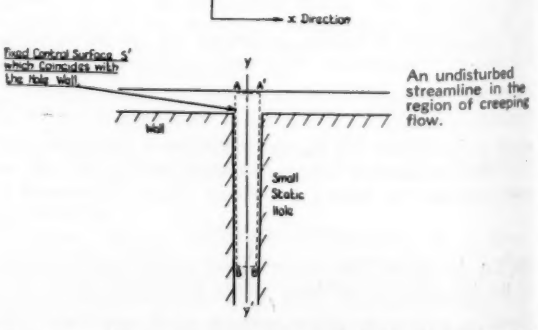

FIGURE 1. Sketch of the small static hole, the undisturbed streamline and the control surface.

Received 9th June 1961.

the integrated shear stresses over a control surface, which coincides with the hole surface, as shown in Fig. 1. Furthermore, there will be no net outflow of momentum from S' in the y-direction.

Applying the momentum theorem for the y-direction, it is apparent, therefore, that the mean pressure over the surface BB' will be equal to that over the surface AA'. Since the latter is in the undisturbed flow, the mean pressure there will be equal to the true static pressure to be measured.

Thus it can be concluded that the pressure registered by a static hole tends to the true value as the hole size tends to zero. The procedure of extrapolating to zero hole size, the curve of pressure versus hole size, in order to deduce the true static pressure, is therefore justifiable.

ACKNOWLEDGMENT

The author is indebted to Dr. B. S. Stratford of the National Gas Turbine Establishment and to Mr. R. I. Tanner of Manchester University, for their helpful suggestions in connection with this problem.

REFERENCE

1. Ray, A. K. (1956). On the Effect of Orifice Size on Static Pressure Reading at Different Reynolds Numbers. *Ingen-Arch.* 24 (3), 171.

The Production of Peak Velocity Profiles

D. C. ROBERTS

IN THE technical note in the August JOURNAL by Morgan and Saunders the values given in the last column of Table I on p. 572 are actually the square roots of the open area ratio.

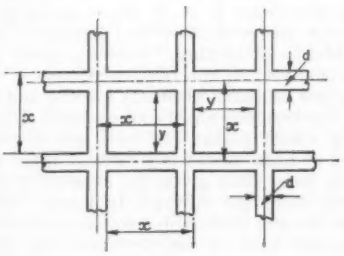

FIGURE 1.

Mesh wires per in. $= t$
Wire diameter $= d$ in.
Wire pitch $= x$ in. $= (1/t)$ in.

For a square mesh as shown above

$$\text{Open area ratio} = \frac{(y)^2}{(x)^2} = \left(\frac{x-d}{x}\right)^2 = \left(\frac{1/t-d}{1/t}\right)^2 = (1-dt)^2$$

The correct values for the open area ratio are given in the following table, column 5; the values given by Morgan and Saunders appear in column 4.

TABLE I

1	2	3	4	5
Screen No.	*Wire. dia. in.*	*Mesh wires per in.*	$(1-dt)$	*Open area ratio* $(1-dt)^2$
1	0·017	24	0·592	0·35
2	0·013	22	0·714	0·51
3	0·030	11·5	0·655	0·43

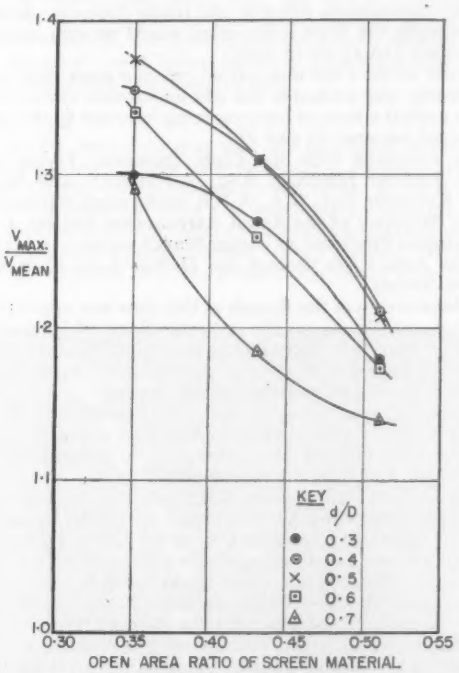

FIGURE 2.

The correct plot of V_{max}/V_{mean} against Open Area Ratio is given on the accompanying Fig. 2.

Mr. P. G. Morgan writes that Mr. Roberts is quite correct in his comments and he regrets the error, which was also pointed out by Mr. N. A. Dimmock.

The Halton Branch is another that has known two existences, first in 1927 and now, from 1950.

IN THE EARLY 1920s the Halton Aero Club was formed at No. 1 School of Technical Training, Royal Air Force, Halton.

The aim of the club was to encourage Aircraft Apprentices, under training at Halton for the engineering trades of the R.A.F., to pursue their aeronautical interest and, under the guidance of members of the Academic and Technical staff, to design and build a series of light aeroplanes to be flown in the many light aeroplane competitions of the period.

From the records now available it has not been possible to verify the actual number of aeroplanes projected or completed, but it is known that in July, 1929 no less than four H.A.C. (designation of the type) aircraft of Club design and construction were entered for the King's Cup and Siddeley Trophy competition. (Should any reader have any details or photographs the Branch Secretary would be very pleased to bring their history up to date.)

Work at the Club was carried out as a spare time activity at evenings and weekends and was undertaken extra-curricula to the normal course of training being followed by the apprentices aged between 16 and 19.

In February 1926 the Club Treasurer, Flying Officer C. H. Latimer Needham B.Sc., A.F.R.Ae.S. and Secretary A. C. Kermode, Esq., B.A., A.F.R.Ae.S., made representation to the Secretary of the Royal Aeronautical Society, Captain J. Laurence Pritchard, to obtain Branch status. In May 1927 Halton Aero Club became the Halton Aero Club Branch of the Society.

Membership of the Branch at this time was approximately 600 but, mainly due to the untiring efforts of Flying Officer Latimer Needham, the membership in 1929 stood at 1577, a Society record at that time, and of which many had been enrolled as Student members of the Society.

Due to changes of policy and a reorganisation of the many hobby societies and clubs at Halton into a single society, it became, very unfortunately, necessary, to disband the Halton Aero Club and thus, the Halton Branch.

In 1935 Dr. B. J. Lynch, B.Sc. and A. C. Kermode, Esq., both members of the Academic staff at Halton, formed "The Aeronautical and Engineering Section" of the Halton Society (as the reformed hobby Society had come to be known) the objects and aims of this new Section being to cater for those apprentices who had shown an interest and desire to hear lectures given by experts from the Aircraft Industry and to arrange visits to manufacturers' establishments, additional to the compulsory syllabus of training. Also, encouragement was to be given for members to prepare and read papers to the section.

These aims seemed so similar to those of the Society's Branches that Dr. Lynch was prompted to approach the Society for reinstatement as a Branch; however, the war intervened and from 1939 to 1948 activities of the Aeronautical and Engineering Section of the Halton Society ceased.

Upon the cessation of hostilities the Section was reformed by an enthusiastic group of the Staff at Halton headed by the late Wing Commander L. A. W. Deane, A.R.Ae.S. and under whose guidance the Section prospered. Wing Commander Deane, or "Dizzy" as he was known, tendered a request to the Society and in May, 1950 the Halton Branch of the R.Ae.S. was re-instated by resolution of the Council.

The membership of the Halton Branch is rather of a unique nature. First, apart from a small number of civilian technical instructional staff, the population of Halton is always floating. Service Staff are subject to the normal postings and movements and therefore only remain at Halton for an approximate period of three years. The majority of the members are aircraft apprentices aged 16-19 undergoing technical training in the ground engineering trades of the Royal Air Force, their course lasting three years, consequently the Branch has a constant incoming of new junior members and outgoing of those who have completed their courses.

Secondly, meetings are held once a week the whole year round, except for the month of August when the Station closes down for annual leave. This causes quite a headache for the Secretary, who has to arrange a full programme over a year in advance. Thirdly, the Branch is probably the only one privileged to have its own distinctive Branch tie, designed at the inception of the Branch.

After the tragic death of Wing Commander Deane in 1951, his many friends both in the Service and the Industry subscribed to a fitting memorial which takes the form of a silver model of a D.H. Comet 1 mounted on a plinth and known as the Laurence Deane Memorial Trophy. The trophy is awarded annually to the Junior Member presenting before the Branch the best paper on an aeronautical subject of his own choice and preparation. Papers are adjudicated by a panel of Senior members and the paper judged the winner at the end of each year is submitted to the Society as an entry for the under-21 class of the N. E. Rowe medal.

Apprentice R. D. Trender's paper "The History and Development of Parachutes and British Ejector Seats" was awarded the first under 21 N. E. Rowe medal in 1957.

The Branch shares a Memorial Lecture "The Viscount Trenchard Memorial Lecture," which is given one year by Halton, the next year by the Henlow Branch.

Meetings are held each Thursday evening and are allocated as follows: The first meeting of each month is Junior Members night during which papers are read and discussions held. One meeting of each month is a Lecture night when we are privileged to hear talks given by experts in their various fields, mainly from the Aircraft Industry. The remaining evenings are devoted to films on aeronautical or allied subjects.

Meetings are held in the Branch's own Headquarters, taken over some two years ago. The building occupies about 80 ft. x 30 ft. and houses a fairly well stocked library and a projection booth equipped with a 16 mm. sound film projector and slide projectors to accept all known sizes of slides and transparencies; an epidiascope caters for projection material not on slides. Most of the work on the building has been and continues to be, carried out by self-help on Junior Members' Nights when no papers are forthcoming.

The Branch is run by two Committees, one of Junior members and the other of Senior members, the two Committees welding the ideas and suggestions of two widely spaced age groups into an extremely satisfactory whole.

Until his death, Lord Trenchard remained President of the Branch and since that date, Air Marshal Sir Owen Jones, the present President of the Society, and Air Vice-Marshal Sir Herbert D. Spreckley have honoured the Branch by their Presidency.

Annual membership fluctuates around 200 although actual attendances at meetings are always lower than that. It is fair to say of Halton that "it is a healthy branch."

This page has recalled many associations between Branches and Aircraft Firms. The Halton link with the Royal Air Force is a direct one and an association of great significance.

The Avro Avian

Following on previous news to save G-EB2M, I am asked by Mr. W. A. J. Wall (*Associate Fellow*), who is taking an active interest, to buy and procure any technical papers or books relating to this aircraft. Will any reader, especially those of the many Flying Clubs who used to fly the AVIAN, who have drawings, maintenance and spares manuals or pilot's notes, please advise me c/o The Royal Aero Club, 119 Piccadilly, W.1.—G.W-W.

Graduates' and Students' Section

The September Film Show

The first film show of the session was held on the 27th September in the new Lecture Theatre. The popularity of these events was demonstrated once again by the size of the audience, over sixty, who were treated to a very varied and enjoyable evening's entertainment.

The films shown covered a wide range of aeronautical and general subjects, varying from the "stick and string" days of the early Vickers aircraft to the complex Atlas missile system, and they gave glimpses of aircraft operations from the snows of the Antarctic to the jungles of Central Africa.

The film "Antarctic Crossing" was shown by popular request, and gave a gripping account of Fuch's and Hillary's crossing of Antarctica with the Commonwealth Antarctic Expedition. It showed that, even with the help of advanced bases and "Snowcat" tractors, a far cry from the equipment of former explorers, the Antarctic still held enough dangers to make the crossing a memorable achievement.

"Blue Streak" gave many their first chance of seeing this de Havilland missile. It was shown undergoing static firing in Cumberland. The transition from testing to operational firing was the theme of "Countdown." This film gave a detailed account of the preparations for the firing of an Atlas Intercontinental Ballistic Missile down the Atlantic Test Range from Cape Canaveral.

"Vickers Aviation History" showed us many of the famous aircraft that have taken to the air from Brooklands from the days of the Brooklands Flying Club and the early motor racing meetings to the present generation of civil air liners.

"Distant Neighbours" showed the effect of aircraft on the life of a family of crofters from the Western Isles of Scotland, whose jobs had taken them to places as far apart as the backwoods of Canada and the Australian Bush. Although fictional, the film showed clearly how many people in isolated places of the world rely on aircraft for essential services such as provisions, "Flying Doctors," equipment and mail.

The evening ended on a slightly horrific note with "Rival World." This showed the fight for survival in Africa between man and the insects, and the efforts of the United Nations Organization to combat the suffering and damage caused by the six-legged hordes.

For those who missed the show, the date to remember is 28th March, when the next Film Show will be held. But there are a lot of interesting lectures before that!

The next Lecture is on 22nd November on "Army Aviation" by Colonel C. D. S. Kennedy
The Winter Dance will be held on 24th November from 8-11.45 p.m. Double Tickets 15/- including refreshments. A few tickets are still available from Mr. J. Wilby, 9 Blenheim Avenue, Highfield, Southampton.

The Section's Accounts

To a new "Hon. Treas." the Graduates' and Students' Section gives the appearance of being the Utopia of accounts. A regular income with, at first sight, no expenditure, should provide an ample expense account for the long cherished Honorary Treasurer's annual holiday.

An annual grant of £25 from the Main Society forms the basis of the Section's finances. This, with huge profits from the Summer and Winter Dances and the bi-annual visit to the Paris Air Salon should give an adequate income to cover the few (?) expenses of the fellow committee members. The remainder could then be neatly accounted for as 'Treasurer's expenses.' How quickly this illusion is shattered.

Using the total income from the tickets to provide the expected high standard of entertainment at the Dances, much hard work is invested for profits which, mathematically, could be called "complex." They are in fact often "purely imaginary" and sometimes even "real and negative." Thus one possible source of profit disappears.

The highly successful visits to the Paris Air Show should result in increases to the Section's bank balance. This, of course, does occur—but only for a very brief period. After the last visit the original cost of £10 10s. 0d. per ticket was reduced to £9 10s. 0d., and the profits to nil, when a refund of £1 was made to each person. (The psuedo-arithmetic "10 guineas minus £1 equals 9 guineas"—see this Journal page for July—was not the Hon. Treasurer "cooking the books" but the author of the article having difficulty with French francs and his slide rule.)

Thus one is left with the Annual Grant, depleted by the Dances, to pay the expenses of the Hon. Sec., Hon. Visits Sec., Hon. Editor and Hon. Etc., the hire of some of the films and the coffee served before each lecture. Perhaps one solution is to prevent, rather than persuade, members to come to Section meetings but this does not seem quite right.

By the end of the year the Honorary Treasurer is left with barely enough to bribe the Auditor and a growing realisation that the word "Honorary" is again applicable.

22nd November

Colonel C. D. S. Kennedy will be lecturing to the Section on some typical functions of *Army Aviation* in various modern armies on the above date. He will talk about the influence of technical and tactical considerations on the type of aircraft required, the pilot and ground crew aspects, and finally speculate about future trends and developments.

It sounds pretty interesting to me!

N.G.T.E. Visit

Six people have said that they are interested in visiting the National Gas Turbine Establishment at Pyestock, Farnborough, Hants., on a Wednesday afternoon. At least four more are required to bring the party up to strength and enable the Hon. Visits Secretary to make firm arrangements. Everyone interested please contact N. R. Craddock NOW at 7 Clitheroe Avenue, Harrow, Middx. (Tel. Field End 7653.)

In his recent lecture to the Section D. F. Ogilvy referred to the Chipmunk, a line-up of which is seen above, as "The only real trainer in service in this country today."

Watch for posters giving details of the 6th December Lecture

THE LIBRARY

Reviews

ALWAYS ANOTHER DAWN. *A. Scott Crossfield with Clay Blair Jnr. Hodder and Stoughton.* 421 *pp. with Index. Illustrated.* 25*s.*

Elimination is a necessary discrimination in autobiography. Scott Crossfield has an amazing story to tell, but initially obscures it with chapters of early life and parentage, giving the impression that he is rather pleased with himself. Nevertheless, his writing is the expression of a strong character. He is among those men who have tested themselves to the utmost—and not merely once, but over many years.

Backed by some 2,000 hours flying in the Navy, and a Master's degree in aeronautical engineering, he obtained a Test flying appointment with the N.A.C.A. at Edwards field in 1950. His task was supersonic research on the Bell X's and Douglas Skyrockets—springing from the magnificent pioneer flights of "Chuck" Yeager, the first man to fly at Mach 1. Even Crossfield's first flight foreshadows the appalling frustrations and disasters of such work. Immediately after stratospheric release from the B.29 launching aircraft the jet of his Bell X-1 flamed out, cabin pressure and electronics faded, and the windscreen iced up on the dive-glide approach to the dried Salt lake used as a landing area for these perilous machines.

In November 1953 he became the first to exceed Mach 2, flying the X.1.A. on the knife-edge of instability. There was keen inter-service rivalry to secure height and speed records. Yeager was Air Force challenger and reached Mach 2·42. At that the winged projectile suddenly "uncorked," tumbling uncontrollably 51,000 feet in fifty seconds, smashing Yeager around in the cockpit: "There is something terrible about the helplessness with which you fall. There is nothing to hold on to and you have no strength. There is only your weight knocked one way and the other. The whole inner lining of the pressurised cockpit is shattered as you are knocked around, and its skin where you touch it is scorchingly hot. Then as the airplane rolls, yaws and pitches through a ten mile fall, you suddenly lose consciousness. You don't know what hit you or where." But Yeager survived.

It was vital for research aircraft to reach far ahead of military combat aeroplanes. Already the first supersonic fighters had arrived at Edwards for investigation of dangerous instability and engine malfunction at high altitude. Designers were laying plans for Mach 3 military machines, but the research aeroplanes had yet to achieve Mach 2·5. In April 1954 the N.A.C.A. completed engineering studies of a design that led the way to the hypersonic Bell X.15 with which much of the rest of Crossfield's story is concerned.

But first there was the steady notching up of speed with existing research vehicles. Mel Apt was selected to set a new speed record for the Air Force using the long delayed Bell X.2. The N.A.C.A. protested at the danger. On the thirteenth flight the rocket burned six seconds longer than before, enabling Apt to drive the X.2 to Mach 3·1 or 2,094 m.p.h.—then the machine, as predicted, cartwheeled out of control with tremendous *g* forces. The pilot blew the nose capsule free, but before he could parachute it hit the desert with tremendous impact. That speed on altitude record had cost eleven years' work, two pilots killed and three X.2's wrecked.

There were lesser perils familiar to all test pilots. Flying the F-100 fighter the fire-warning light came on. Under it was a notice: IF LIGHT REMAINS ON, BAIL OUT. Crossfield comments: "A hell of a sign to put in a cockpit—it inhibits thinking." He stayed in, to make the first dead engine landing for that type of machine.

There is a familiar ring about questions of design. Enquiring why a battery known to be immensely fragile was used, he was told: "Don't ask me, I just work here and we have a thousand bosses in every corner of the Government." And of an early scheme to put a rocket aircraft in space using a V-2 booster: "Because it came from the Industry, the proposal got the full N.A.C.A. treatment—that is to say, a rejection, complete with technical data attached."

Perhaps growing a little out of love with N.A.C.A., Crossfield in 1956 wished himself into the North American Company as adviser and test pilot of the X-15 project. Everything about it was new and challenging; each problem a minor crisis. The story of the evolution is fascinating.

In the autumn of 1958 six years from its inception, four from approval by the N.A.C.A. Aerodynamics Subcommittee, three years from acceptance of tender, and right on schedule, the X-15 was a reality. Despite temporary substitution of heavier power plant and addition of full instrumentation, the machine was only one hundred pounds overweight—an unprecedented achievement. It represented 100,000 engineering manhours, and at an eventual cost of $40 million for each of three aeroplanes, in terms of weight the X-15 was worth three times as much as solid gold.

Edwards Air Force base had by then matured into a huge citadel as the world's premier test flying laboratory. The Air Force was "wringing out" the F.105, F.106 and F.107. Industry was testing the new family of jet air liners: the 107, DC-8 and 880. The N.A.C.A. plant, grown from two sheds and now splendidly housed, was awaiting the revolutionary X-15 that would make all other aircraft seem insignificant in achievement.

Item aftem item sabotaged commencement of tests: valves, regulators, and long developed equipment of every description failed, as it so commonly does, under quite unexacting tests. For three months the machine was grounded by one source of trouble alone—the A.P.U.'s peroxide-driven turbine, giving electrical and hydraulic power for instruments and controls.

Eventually to avoid an adverse press, with a hundred reporters, photographers and T.V. cameramen camped along the lake-bed, the first free flight was made. In the moments before release from the cradle beneath the wing of the 8-jet B.52, Crossfield found that the pitch mode of the automatic control had failed. He decided to make the scheduled engineless drop, and gliding like a brick at 500 m.p.h. from 38,000 feet, reached the salt bed in five minutes—only to find uncontrollable oscillations on flattening out owing to lag in the hydraulically-operated elevator.

The powered X-15 No. 2 which was having the almost endless ground tests which are preliminary to flight, blew up while being purged of hydrogen peroxide. She was rebuilt in weeks. For strategic reasons, not unknown in our own industry, it was essential to make an early flight. Finally, on 17th September she was launched, and all eight rockets were fired to give impetus. Crossfield's only comment is: "Instantly it was apparent we had a beautiful airplane, firm without yaw and pitch common to most high performance planes." Four minutes after launch the fuel load of 4 tons of Lox, 5 tons of Walc, and 600 lb. of hydrogen peroxide, had burnt out. Ten minutes from start, he was touching down at 200 m.p.h., stopping a bare 100 yards from a ditch, only to find he had a furious fire from an alcohol leak.

In the first year the X-15 was carried aloft fifteen times. Two of these were planned captive flights; nine were attempts to fly but abandoned due to anything from radio failure to more serious faults; one was the first glide; and three were rocket powered of which two began with serious emergencies. Thereafter the X-15 began to shape up, and

in the next six months there were sixteen attempts at rocket powered flights of which only three were cancelled.

With the first attempt at flying the prototype big single rocket designed to blast the X-15 to the fringes of space, Crossfield's story draws to a conclusion. After an automatic shut-down he presses the re-start switch. "It was like pushing the plunger on a dynamite detonator." The X-15 blew up with incredible force. The 16,000 lb. of fuel had ignited spontaneously. With an acceleration of 50 *g* his cockpit was shattered and hurled forward with him strapped inside. He was unharmed. "There was no panic, no fear."

As he says earlier in the book: "Fear, I think, is something a man feels when he runs out of things to do . . . . Pilots are occasionally startled like everyone else. The normal re-action is to look for the cause. The pilot learns from long experience to determine the cause swiftly and positively. Then he turns to action. There are set procedures . . . . I have been startled in an airplane many times. This, I may say, is almost routine for the experimental test pilot. But I can honestly say I have never experienced real fear in the air. The reason is that I have never run out of things to do." But perhaps it is also because he considers man is seeking answers—about himself, his universe and his God.—H. J. PENROSE.

AEROFOIL SECTIONS. *Dr. F. W. Riegels. Translated from the German by D. G. Randall. Butterworths, London.* 1961. *Illustrated. Index.* £10.

A fundamental requirement for the design of any aircraft is a knowledge of the properties of the sections of wings so that a choice can be made of that best suited for the desired operational use. This translation of a German work, originally published in 1958, provides a wide range of data and of the aerodynamic knowledge upon which the designs of aerofoils have been based. The experimentally investigated families include Göttingen profiles; four and five figure N.A.C.A. series of profiles and their extension by the D.V.L.; laminar profiles; the theoretical developed families of Joukowsky, Kármán-Trefftz and Betz-Keune together with the Hyperbola family. Different chapters deal with wind tunnel methods and measurements; special problems of the quality of the surface and of cavitation; flaps; boundary layer control by suction and blowing. Considerable space (40 pp.) is devoted to the theories of wing profiles and the book concludes with more than half its volume devoted to Tables of geometrical and aerodynamic data and to a catalogue of theoretical and experimental results. The scarcity of published data on very thin aerofoils is apparent.

This expensive, but exceedingly attractive and useful book, includes the essence of aerofoil theories and the established formulae for the calculation of various characteristics, backed by copious references to original papers in each of the chapters, plus an author and a short subject index. The pioneer investigations undertaken by both Germany and America are well covered in the text and in the tabulated data and graphs. The theories of wing profiles by Theodorsen, Goldstein, Lighthill, Thwaites and others receive mention, but the text deals with Wittich's development of the procedure originated by Theodorsen. Other theoretical chapters deal with boundary layers and with supersonic flow.

Some familiarity with the book is necessary to find what a user may be looking for. The key lies in the catalogue on page 197 (not paged in the general contents list) of all the aerofoils for which the theoretical and experimental results are plotted. Not every aerofoil of a series is included since clearly a selection has to be made, as for example in the R.A.F. series, but the modern R.A.E. sections 100-104 have not been omitted. The tables giving a collection of geometrical and aerodynamic data are consecutive either under the running numbers of the various research institutions or grouped together such as for profiles with high-lift devices. There is no tie-up between the tables and the catalogue, but many references to the latter are given in the text.—J. L. NAYLER.

FLIGHT BRIEFING FOR PILOTS, Vol. I. *A. H. Birch and A. E. Bramson. Pitman, London.* 182 *pp.* 15s.

It is, perhaps, a reflection on the state of private flying in the United Kingdom that apart from the well-known Service publications so few manuals of elementary flying instruction have been produced in this country. The publication of this book by writers who are extremely well qualified in their profession is therefore particularly welcome. Bearing the imprimatur of the Panel of Examiners of the Guild of Air Pilots and Air Navigators, it should find widespread acceptance among student pilots, for whom it is primarily intended, and should also be most helpful to students for the Flying Instructor's Course.

Flying instruction is a costly business and it is the aim of the instructor to extract the maximum value from every hour spent in the air. If the student starts the exercise with a clear idea of its aim, procedure and the principles involved he is enabled to build a sound practical structure on a firm theoretical foundation. This is the aim of *Flight Briefing for Pilots.*

The book opens with a non-mathematical account of the fundamentals of flight. In this chapter, as throughout the book, the numerous excellent diagrams by one of the co-authors are a useful feature.

The remainder of the manual is devoted to a chapter-by-chapter treatment of the exercises involved in the syllabus for the Private Pilot's Licence. Each exercise is covered in sufficient but not burdensome detail and the writers have avoided the error of leading the student too hastily into the finer points of technique. At the same time full account is taken of the changed characteristics and superior equipment of modern training aircraft.

The approach to the subject is at all times simple, yet smoothly professional and the authors clearly have in view the production of pilots who are not only manually competent but also intelligently aware of the forces acting on their aircraft.

Good examples of the technique are to be seen in the chapters on Spinning and Steep Turns. The spin is described in the text, while the accompanying diagram shows the relative air flow and the resultant behaviour of the wing. In the case of the steep turn the relationship between air speed, bank and wing loading is clearly demonstrated.

In view of the importance of adherence to the many regulations on controlled air space it is to be regretted that the opportunity was not taken to give greater prominence to this subject in the chapter on Pilot Navigation. It is unfortunate that private flying is hedged around with many restrictions, but as they are not likely to be relaxed appreciably it is as well that the student pilot should be thoroughly aware of them from his first day in the air.

As a primer of flight this book is to be recommended to all who are actually learning to fly and to those who hope to have the opportunity in the future. With its companion volume on Advanced Flying, which is awaited with interest, it should prove a most valuable aid to student pilots and their instructors.—R. SEARLE.

ANGEWANDTE STROMUNGSLEHRE (Applied Fluid Dynamics). *In German. W. Albring. Steinkopff, Dresden and Leipzig.* 1961. 380 *pp. Diagrams. DM.*43.

Individuality in expression and presentation, together with the quality of paper, print and lay-out, mark this publication with distinction. The author, Professor at the Technical University at Dresden and Director of its Institute for Applied Fluid Dynamics, adds to the large number of text-books on this subject not "just another one"—excepting perhaps that it is written in German and produced outside the Western World—nor does he merely help to close the gap, apparent in the list of German books in this field, since long before the last war.

Considering the subjects of incompressible fluids, gas-dynamics and viscous effects in three major parts, the author presents, in this publication of his lectures to students of mechanical engineering, the link between the principles of mechanics and the methods of solving problems of practical application, such as conductivity of heat in pipes, pressure distribution over aerofoil sections (Moriya, Riegels) and its inverse problem (Helmbold, Keune).

The aeronautical engineer, dealing with viscous effects may also be interested in the conception of the Hagen number and in the experimental data on axi-symmetric bodies at various Reynolds numbers, or in the presentation of analogies to plane hydrodynamic flow.

In all fields of applied fluid dynamics the author confines himself to well-selected problems. Of the 140 references in the up-to-date Bibliography, some 30 are from Eastern Germany, the rest mainly from the West. This book, certainly not written in a hurry, makes stimulating reading, particularly for advanced students and mechanical engineers.—E. S. KRAUSS.

STRESS CONCENTRATION AROUND HOLES. *G. N. Savin. Pergamon, London.* 1961. 430 *pp. Diagrams.* 84*s.*

The book under review is a translation, originally made for the D.S.I.R., of the Russian book by Savin published first in 1951; and its publication, now in its complete form, will be welcomed by many mathematicians and engineers interested in elasticity problems. However, it seems a pity that the publishers have found it necessary to reproduce such an important book by the offset-lithography process which renders some of the equations nearly illegible and some of the diagrams useless. It may be pertinent to remark here that the Ministry of Supply (as it then was) produced a summarised report on this book at least five years ago, giving the relevant data in a graphical form which is most helpful for design use.

Since it would be nearly impossible to cover all aspects of stress concentration fully in one volume, this book is confined to the two-dimensional problem of stresses around holes in a plate. It is divided into eight chapters, each designed to be self-contained, and begins with a general one on the fundamental equations in the theory of plane elasticity. The author then deals pretty thoroughly with the question of holes in plates under various load conditions, circular, elliptical, rectangular and triangular holes in isotropic plates, circular and elliptical holes in anisotropic plates, stresses beyond the elastic limit round circular holes and the effects of reinforcement round the holes. The last chapter gives briefly some comparisons of experimental data with theory.

Results throughout the book are given in tabular and graphical form and are thus reasonably easy to use, but the reviewer would like to point out that Table 21 appears to be based on the work of Jeffery (1920) which has since been proved incorrect by Mindlin and others, and that readers interested in the problem of stresses around a circular hole near the edge of a semi-infinite plate under tension would be well advised to look at the paper by Mindlin in the Proceedings of the S.E.S.A., Vol. V, No. 2 (1948) or R.Ae.S. Structures Data Sheet 06.00.01.—M.E.M.

MISSILE CONFIGURATION DESIGN. *S. S. Chin. McGraw-Hill, London.* 1961. 279 *pp. Diagrams.* 85*s.* 6*d.*

This book outlines the first steps in determining the external configuration of a missile. It is written from the point of view of an aerodynamicist but one who is commendably "system minded," frequently drawing attention to points where structural, propulsion and guidance considerations bear on the design. The book has little that will be unfamiliar to offer the professional aerodynamicist; however, it should be of value to those of other specialisations who wish to broaden their knowledge of missile technology and particularly to systems engineers concerned with feasibility or design studies.

The first three of its fourteen chapters are devoted to the estimation of aerodynamic force and moment, mainly in supersonic flight but making some reference to the subsonic regime. There follows a chapter on performance which describes the use of step-by-step methods and the Breguet equations. Chapters five to nine are concerned with missile stability and control, developing the aerodynamic transfer functions for two degrees of freedom and including some discussion of more complex motions. Three further chapters discuss air loads, launching and dispersion problems, and the book concludes with chapters on propulsion and structures. With the exception of a few of the diagrams which are too small, the book is well produced to these publishers' usual high standard.

The book would have benefitted from a more careful preparation, a number of trivial errors being noted at a first reading; also its style might have been "more optimum," to borrow the author's own expression. Of greater importance, the book lacks at the beginning the thorough definition of conventions and axes which is necessary to clarify stability and control problems. At one point the author himself falls into the trap and fails to distinguish between the positive and negative control moment derivatives associated with canards and tail controls. In consequence his discussion of static margin loses clarity. As a further criticism, the symbols used are not always the standard ones nor are they completely consistent throughout the book, although each chapter does have a table of symbols. This and the way jargon is introduced, often without explanation, is unfortunate in an elementary text.

To its credit, the book covers a great deal of ground with conciseness and clarity. Some fringe topics are necessarily skimped (the reference to ballistic missile design being a case in point), but in general it is a straightforward practical book, worth the attention of any missile engineer, except perhaps the aerodynamics experts.—P. J. GOULTHORPE.

GAS SAMPLING AND CHEMICAL ANALYSIS IN COMBUSTION PROCESSES. AGARDograph 47. *G. Tine. Pergamon. Oxford, 1961. 94 pp. Diagrams.* 42*s.*

This book is a survey of the experimental techniques used at the present day in the sampling and analysis of reacting combustible mixtures and combustion products, and is based on a review of published work and on discussion with those engaged in the field. The book is not comprehensive in that it does not deal with old established techniques such as Orsat, Haldane, and Bone-Wheeler, but concerns itself with the methods of analysis developed in recent years such as gas chromatography and instrumental analysers such as these based on infra red absorption.

The first part of the book is devoted to problems of sampling, and deals with difficulties encountered in inducing a representative gas sample into the entry to the sampling probe, and in ensuring that the sample reaches the analyser unchanged in composition. Various methods of sampling and quenching are described, the probable accuracy to be obtained from each is discussed, and outline designs of some of the various types of sampling probe currently employed are provided.

The second part of the book is concerned with the various techniques which can be used for analysing the gas sample and the methods which can be used for estimating any given component of a sample are described briefly. The limitations of each method or instrument are defined and some indication of the amount of sample required for analysis is given. The methods discussed include spectrometry, mass spectrometry, and gas chromatography among those more commonly encountered.

The book should be valuable to anyone engaged in the analysis of internal combustion engine performance and to anyone engaged in research on related topics. The book is well written, and represents a condensation of a great deal of useful information.—D. G. MARTIN.

APPLIED THERMODYNAMICS. *S. H. Bransom. Van Nostrand, London. 230 pp. Diagrams. Paper back 22s. 6d. Cloth back 30s.*

When faced with yet another book under a title such as this, a reviewer may perhaps be excused for seeking at once for some special reason for its existence. In this particular case the author explains in his preface that it is his intention to try to make thermodynamics less dull as a subject and so help to avoid misunderstanding of its basic principles. This object is to be achieved by adopting a practical approach to the clarification of difficult concepts. Without doubt this is a worthwhile aim, but it is doubtful if there is real hope of achieving it in a book of this size.

The first three chapters deal at some length with definitions and with the First and Second Laws of Thermodynamics and their consequences. In view of the preface the absence of extensive reference to practical applications is somewhat surprising although these chapters are adequate in their own right.

Chapters 4 and 5 on the presentation and nature of the properties of real fluids are brief but adequate references are given for the student who requires more detail.

Chapter 6 deals with applications of the principles dealt with earlier but it is doubtful if the treatment is adequate either for the chemical or for the mechanical engineering student and here there are not sufficient references to make good the deficiency.

Of particular interest to the chemical engineer, Chapters 7 and 8 introduce free energy functions and deal with a variety of equilibrium conditions but it is difficult to regard the material presented as forming more than an outline of the work required. This brevity may even be misleading, as for example in Section 8.4 on Electrical Cells.

It might be considered that the author's real interest lies in the subject matter of Chapter 9—an elegant treatment of a number of problems arising in distillation processes, which makes this a worthwhile reference for students.

Throughout the book a good selection of examples is given and in some cases notes on the solution of the more difficult problems are included.—H. BILLETT.

Additions to the Library

Advances in the Aeronautical Sciences. Volumes 3 and 4. (Proceedings of the Second International Congress in the Aeronautical Sciences, Zürich, 12th-16th September 1960.) Pergamon Press, London. 1961. Vol. 3. 592 pp. Vol. 4. 1,206 pp. Illustrated. *To be reviewed.*

Aeronautics and Astronautics. An American Chronology of Science and Technology in the exploration of Space 1915-1960. E. M. Emme. U.S.G.P.O., Washington. 1961. 240 pp. $1.75. N.A.C.A.-N.A.S.A. activities started 12 years after the first flight in America. This book forms an interesting commentary on the efforts to catch up on those lost dozen years.

Air Freight and Anglo-European Trade: a Sample Study. K. R. Sealy and P. C. L. Herdson. Privately published. 1961. 87 pp. A survey, made possible by a grant from the London School of Economics, "to acquaint manufacturing industry at large, and the air transport industry, with the current and future competitive position of air freight by examining in detail the costs involved in distribution of goods from factory to consumer both by air and surface transport."

Atlas of the Other Side of the Moon. N. P. Barabashov, A. A. Mikhailov and Yu. N. Lipskiy. Pergamon, London. 1961. 171 pp. Illustrated. 50s. *To be reviewed.*

Basic Physics of the Solar System. V. M. Blanco and S. W. McCuskey. Addison-Wesley Publishing Company, Inc., London. 1961. 307 pp. Illustrated. 64s. Evolved from a series of lectures, given by the staff of the Department of Astronomy, Case Institute of Technology, to research scientists, engineers and supervisory personnel engaged in work relating to interplanetary space, but with limited knowledge of the astronomy of the solar system. Examples of computations in celestial mechanics and practice problems are included.

Bibliographie der Veröffentlichungen über den Leichtbau und Seine Randgebiete im Deutschen und Ausländischen Schrifttum ans den Jahren 1955 bis 1959. (Bibliography Publications on Light Weight Constructions and Related Fields in German and Foreign Literature from 1955 to 1959 (continuation). H. Winter. Springer-Verlag, Berlin. 1960. 692 pp. DM.80 The first part of this book, which covered the period 1940-1954, was reviewed in the JOURNAL for February 1957 (p. 139). This valuable bibliography has now been extended in the present volume to cover the years 1955-1959.

Civil Air Regulations and Flight Standards for Pilots. Aero Publishers Inc. 23rd Edition. Aero Publishers, Los. Angeles. 1961. 160 pp. Illustrated. $4.50. The fact that this has reached its 23rd edition indicates (*a*) that there is a demand for the publication and (*b*) that there are frequent changes in American Air Regulations. The book is made up of extracts from relevant civil air regulations and of chapters of helpful instructional material with explanatory drawings, all American.

Combustion, Flames and Explosions of Gases. 2nd Edition. Bernard Lewis and Guenther von Elbe. Academic Press, New York. 1961. 731 pp. Illustrated. £7 17s. 6d. The second edition of the book published in 1951 and reviewed in the JOURNAL for January 1952 (p. 59). In this review the book was well recommended apart from part 4. The detailed criticism made of this part seems to be still justified, although other parts of the book, particularly on combustion waves, have been revised.

Elements of Flight Propulsion. Joseph V. Foa. John Wiley & Sons, London. 1961. 445 pp. Diagrams. £5. *To be reviewed.*

Experimental Methods in Combustion Research. Edited by J. Surugue. (AGARD publication.) Pergamon, Oxford, 1961. 300 pp. Illustrated. £5 5s. 0d. *To be reviewed.*

Flight Rules and Air Traffic Procedures. A Training Manual for Aviation Personnel. Hubert G. Daniels. Richard Carl Schmidt, Brunswick. 1961. 196 pp. DM.21. Although published in Germany, this book is in English. Twenty-two I.C.A.O. publications have been used in its preparation and its chapters deal with such items as rules, air traffic control, altimeter setting procedure. Notam Code, radio telephony procedures, abbreviations and symbols and so forth. The book is plentifully illustrated with diagrams and it is well indexed. The price is equivalent to slightly under £2.

Fokker—The Man and the Aircraft. Henri Hegener. Harleyford Publications, Letchworth. 1961. 224 pp. Illustrated. 45s. *To be reviewed.*

Fundamental Data Obtained from Shock-Tube Experiments. AGARDograph 41. A. Ferri (*Editor*). Pergamon Press, London. 1961. 415 pp. Illustrated. 84s. *To be reviewed.*

Fundamentals of Aerodynamic Heating. Robert Wesley Truitt. The Ronald Press Company, New York. 1960. 257 pp. $10. *To be reviewed.*

Handbook of Meteorological Instruments. Part II. Instruments for Upper Air Observations. Meterological Office. H.M.S.O., London. 1961. 210 pp. 25s. A companion volume to Part I (Instruments for Surface Observations) published in 1956. "Upper air" goes to heights of about 40 km. An interesting chapter on historical development starts with Pascal's observations

in 1643 and ends with the 1957 launch of the Soviet earth satellite.

Handbook of Supersonic Aerodynamics. Volume 6, Section 20. Wind Tunnel Instrumentation and Operation. R. J. Volluz. U.S.G.P.O. Washington. 1961. Sectional Pagination. Illustrated. $3. *To be reviewed.*

The History of Airships. Basil Clarke. Herbert Jenkins Ltd., London. 1961. 194 pp. Illustrated. 21s. *To be reviewed.*

An Introduction to Information Theory. F. M. Reza. McGraw-Hill, New York. 1961. 496 pp. £5 4s. 6d. *To be reviewed.*

An Introduction to the Properties of Engineering Materials. K. J. Pascoe. Blackie & Sons, London. 1961. 295 pp. Illustrated. 35s. *To be reviewed.*

Jet Engine Manual. E. Mangham and A. Peace. 3rd Edition. Newnes, London. 1961. 155 pp. Illustrated. 15s. Not a manual in the sense of a repair manual but a student's simple explanatory textbook set out in the form of question and answer. Practical rather than theoretical.

Jungle Pilot. The Life and Witness of Nate Saint. Russell T. Hitt. Hodder & Stoughton, London. 1960. 303 pp. Illustrated. 16s. The story of Nate Saint an American pilot who, after a tour of duty in the U.S. Air Force, joined The Missionary Aviation Fellowship in its early days and with four other missionaries, was killed in 1956 by the Auca Indians in a remote part of Ecuador. Incorporating much of Saint's own writings the book tells of the difficulties encountered in their jungle flying, the ingenious devices invented and developed by Saint and the planning of "Operation Auca" which made the first contact with the isolated and savage Auca Indians.

Lectures on the Calculus of Variations. Oskar Bolza. Chelsea Publishing Co., New York. 1961. 271 pp. $1.19.

Calculus of Finite Differences. Charles Jordan. Chelsea Publishing Co., New York. 1960. 652 pp. $6. Two reprints, the first of a University of Chicago press item (original publication 1904), the second of a book for statisticians and computors now in its second edition.

Modern Airmanship. 2nd Edition. Edited by Neil D. Van Sickle. D. Van Nostrand, London. 1961. 802 pp. Illustrated. 73s. 6d. The first edition, which appeared in 1957, was reviewed in the JOURNAL for December 1957 (p. 842). The criticisms made of it there appear to apply still to the new edition.

National Airport Plan, Fiscal Years 1962-1966. U.S. Federal Aviation Agency, U.S.G.P.O., Washington. 1961. 230 pp. 29s. 3d. A Five Year Plan by the U.S.F.A.A. taking into consideration past growth of air transport requirements. Tables are given for each state wherein "communities" are listed, expected development by 1966 and, finally, "recommended airport development 5 year plan.

The Observer's World Aircraft Directory. William Green. Frederick Warne, London. 1961. 354 pp. Illustrated. 15s. There have always been at least two "drawbacks" to JANE'S. One is its price, if one wishes to make one's small nephew a present, and the other is its non-portability. These two drawbacks, at least, are not found in this book. It is difficult to imagine a more acceptable present for the young spotter-type and it will be equally acceptable to the more mature enthusiast. There is more to the volume than a listing of the world's aircraft (and their details) such as a country-by-country commentary, insignia of the world's air forces, and so on.

Proceedings of the Society for Experimental Stress Analysis. B. E. Rossi and C. H. Winters (*Editors*). Westport, Conn., Society for Experimental Stress Analysis. 1961. 208 pp. Illustrated. Price unknown. This well-known publication has now progressed to letterpress printing, instead of the previous photo-reproduction method, and the presentation is now of a high quality. The 30 papers cover the usual wide range of stress analysis problems, including a number of photo-elastic studies; the 1960 William M. Murray Lecture "The Role of Stress Distribution in Fatigue" is by R. E. Peterson.

Radioisotope Applications Engineering. J. Kohl, R. D. Zentner and H. R. Lukens. D. Van Nostrand, London. 1961. 562 pp. Illustrated. 124s. Described as "a sourcebook for every user or prospective user of radioisotopes" this covers basic principles, health and safety precautions, licensing procedures and many types of applications, including measuring flow, friction and wear, radiography, thickness and density gauging, and radiation processing and process engineering.

Shock and Vibration in Linear Systems. Paul A. Crafton. Harper & Brothers, New York. (Hamish Hamilton, London.) 1961. 415 pp. 70s. *To be reviewed.*

Space Navigation. V. P. H. Weems. AGARD. 1961. 22 pp. No price. A paper read at the AGARD Seminar at the University of Southampton in July 1961.

The Strategic Air Offensive Against Germany. 4 Volumes. Sir Charles Webster and Noble Frankland. H.M.S.O., London. 1961. Vol. I, 522 pp. Vol. II, 322 pp. Vol III, 322 pp. Vol. IV, 530 pp. Illustrated. Index. 42s. each Volume. *To be reviewed.*

Titanium Production Methods in the Aircraft Industry. Imperial Chemical Industries. 1960. 92 pp. Illustrated. No price. Proceedings of a Symposium held at the I.C.I. Titanium Plant in May 1960. Twelve papers, one of which deals with titanium in aircraft manufacture and another with manufacturing experience with the Rolls-Royce "Conway" by-pass duct. Discussions are also recorded.

U.S. Army H-25 Helicopter Drop Test. James W. Turnbow. Flight Safety Foundation, New York. 1960. 94 pp. Illustrated. No price. A report of an exploratory, experimental study.

Wings on my Sleeve. Eric Brown. Arthur Barker Ltd. London. 1961. 191 pp. Illustrated. 21s. *To be reviewed.*

Writing a Technical Paper. D. H. Menzel *et al.* McGraw Hill. 1961. 132 pp. 15s. It is a moot point whether authors should be encouraged but if they must, this book—by Americans—will contribute to lucidity of expression and attempts at style, *e.g.* "All editors must battle continually against (this) unintelligble prose, which goes by various names: engineerese, geologese, officialese, governmentese, Federal prose, gobbledegook, bafflegab, no-English, and sciench."

Reports

AERODYNAMICS

BOUNDARY LAYER *see also* THERMO-AERODYNAMICS

Some simple solutions to the problem of predicting boundary-layer self-induced pressures. M. H. Bertram and T. A. Blackstock. N.A.S.A. T.N. D-798. April 1961.—(1.1.0.4 × 1.4).

Regime of frozen boundary layers in stagnation region of blunt reentry bodies. N. T. Grier and N. Sands. N.A.S.A. T.N. D-865. May 1961.—(1.1.0.4 × 1.9.1).

Turbulent skin-friction and heat-transfer coefficients for an inclined flat plate at high hypersonic speeds in terms of free-stream flow properties. J. F. Schmidt. N.A.S.A. T.N. D-869. May 1961.—(1.1.3.4 × 1.9.1).

Investigation of boundary-layer suction on a 20-calibre ogive cylinder at Mach numbers 2·5, 3·0, 3·5, and 4·0. W. T. Strike and S. Pate. A.E.D.C. T.N.-61-66. June 1961.

The application of suction-type boundary-layer control on the ogive was investigated over a unit Reynolds number range

from 0·07 to $1·03 \times 10^6$ per inch with the model at zero angle of attack. Some additional data were obtained at 2-deg angle of attack at Mach number 3.—(1.1.5.4).

The compressible turbulent boundary-layer on a flat plate with transpiration cooling. I. Measurements of heat transfer and boundary-layer profile. E. R. Bartle and B. M. Leadon. Convair Sc. Res. Lab. Res. Report 11. *May* 1961.
Measurements of heat transfer coefficients and recovery factors at Mach number 2 and 3·2 on a porous flat plate with gaseous nitrogen injection are reported.—(1.1.2.4 × 34.3.4 × 1.9.1).

Drag measurements on circular cylinders and spheres in the transition regime at a Mach number of 2. *A. K. Sreekanth. U.T.I.A. Report* 74. *April* 1961.—(1.1.2.4).

Three-dimensional boundary layer flow. H. Schlichting. D.F.L. Bericht 150. 1961. *In English.*—(1.1).

Experimental investigation of flow separation associated with a step or a groove. I. Tani et al. *Aero. Res. Inst. Tokyo. Report* 364. *April* 1961.—(1.1.4.1).

COMPRESSIBLE FLOW *see also* FLUID DYNAMICS
INTERNAL FLOW
LOADS
TESTING AND INSTRUMENTS

Reaction-resisted shock fronts. J. F. Clarke. C.o.A. Report 150. *May* 1961.—(1.2.3.2).

Reentry Physics Program. Semiannual Technical Summary Report to the Advanced Research Projects Agency. Lincoln Lab. M.I.T. 31st *Dec.* 1959, 30th *June* 1960, 31st *Dec.* 1960.—(1.2.3.2 × 1.4.4 × 1.12 × 26 × 13).

*Hypersonic flow-blast analogy. J. Lukasiewicz. A.E.D.C.-T.R.-*61-4. *June* 1961.—(1.2.3.2 × 1.6.1).

*The approximate influence of base-drag on the optimum shape of axi-symmetric configuration in linearized supersonic flow. P. J. Zandbergen and F. van der Walle. N.L.L.-T.N. G.*14. *Nov.* 1960.—(1.2.3.1 × 1.10.1.2).

Instability of shock wave on thin airfoil in high subsonic flow. K. Karashima. Aero. Res. Inst. Tokyo. Report 363. *March* 1961.—(1.2.1.2).

CONTROLS *see also* STABILITY AND CONTROL

*Normal-force and hinge-moment characteristics at transonic speeds of flap-type ailerons at three spanwise locations on a 4-per cent-thick sweptback-wing-body model and pressure-distribution measurements on an inboard aileron. J. F. Runckel and G. Heiser. N.A.S.A. T.N. D-*842. *May* 1961.—(1.3.1.1 × 1.6.1 × 33.2.3.2).

FLUID DYNAMICS *see also* BOUNDARY LAYER
COMPRESSIBLE FLOW
LOADS

*A semigraphical method of applying impact theory to an arbitrary body to obtain the hypersonic aerodynamic characteristics at angle of attack and sideslip. C. M. Jackson. N.A.S.A. T.N. D-*795. *May* 1961.
Included in the presentation is the derivation of the necessary equations, general application procedure, specific application to a blunted elliptical cone at an angle of attack of 40° and at an angle of sideslip of 0°, and a discussion of the graphical errors and areas of application. The present method requires only one graphical construction for any combination of angle of attack and sideslip.—(1.4 × 25.2).

A state-of-the-art survey of some aspects of the aerodynamics of highly rarefied gases. G. N. Patterson. (First interim report only). U.T.I.A. Review 18. *March* 1961.
A state-of-the-art survey of the mechanics of rarefied gases: properties of molecules and their motion, distribution function, molecular scattering, properties of molecular collisions, Boltzmann equation, Maxwell transfer equations, transfer properties of a gas in molecular equilibrium, Boltzmann equation for free molecule flow, reflection phenomena, free molecule aerodynamics, molecular beams, Boltzmann relation as an integral equation, kinetic model of the Boltzmann equation, basic equations for an isolated body in near-free-molecule flow. An interim report only.—(1.4 × 32.2).

Stability of plane Poiseuille flow between flexible walls. F. D. Hains and J. F. Price. Boeing Sc. Res. Labs. Report D1-82-0092. *February* 1961.—(1.4).

*One-dimensional flow of dissociated diatomic gases. G. R. Inger Douglas Report SM-*38523. *May* 1961.—(1.4).

*A flow model for hypersonic rarefied gasdynamics with applications to shock structure and sphere drag. N. Rott and C. G. Whittenbury. Douglas Report SM-*38524. *May* 1961.—(1.4 × 1.2.3.2).

*Determination of the interference-effects between a ringwing and an axi-symmetric fuselage. F. van der Walle. N.L.L.-T.N. G.*7. *Sept.* 1958.—(1.4 × 1.10.1.2).

Determination of the aerodynamic characteristics of supersonic speeds of ringwings combined with axially-symmetric fuselages. F. Van der Walle. N.L.L.-T.N. G. 2. *February* 1958.—(1.4.1.2.3.1 × 1.10.1.2).

INTERNAL FLOW *see also* TESTING AND INSTRUMENTS

*Pressure measurements on three open nose air intakes at transonic and supersonic speeds with an analysis of their drag characteristics. J. C. Gibbings. C.P.*544. 1961.
Tests on three open nose air intakes at zero over a Mach number range of 0·80 to 1·82 are described. Two of the cowls had sharp lips and the third a rounded lip. External pressure recoveries and drags were obtained for a range of mass flow ratios.—(1.5.1 × 1.2).

*Some surge investigations on a low speed compressor. R. C. Turner and R. A. Burrows. C.P.*548. 1961.—(1.5.2.1).

LOADS *see also* COMPRESSIBLE FLOW
CONTROLS
WINGS AND AEROFOILS

Investigation at transonic speeds of the loading over a 45° sweptback wing having an aspect ratio of 3, *a taper ratio of* 0·2, *and N.A.C.A. 65A*004 *airfoil sections. J. F. Runckel and E. E. Lee. N.A.S.A. T.N. D-*712. *May* 1961.—(1.6.1 × 33.1.1).

Transonic loads characteristics of a 3-*per cent-thick* 60° *delta-wing-body combination. J. M. Swibart and W. E. Foss. N.A.S.A. T.N. D-*830. *May* 1961.
An investigation has been made in the Langley 16-foot transonic tunnel to determine the aerodynamic loading characteristics of a 3-per cent-thick (N.A.C.A. 65A003 airfoil sections), aspect ratio 2·06, 60° delta-wing—body combination at Mach numbers from 0·80 to 1·05 and at angles of attack to 26°. Pressure distributions and tabulated pressure coefficients are presented for the range of Mach numbers and angles of attack.—(1.6.1 × 1.4).

*Unsteady aerodynamic forces on a slender body of revolution in supersonic flow. R. Bond and B. B. Packard. N.A.S.A. T.N. D-*859. *May* 1961.
Linearised slender-body theory is applied to the computation of aerodynamic forces on an oscillating, or deforming, body of revolution in supersonic flow. The time dependence is taken to be sinusoidal. The apparent mass approximation is obtained for a body of small radius. Specific calculations are performed for a body in rigid motion.—(1.6.3 × 1.2.3.1 × 33.1.1).

Theory of the flight of airplanes in isotropic turbulence; review and extension. B. Etkin. U.T.I.A. Report 72. *February* 1961.—(1.6.3 × 1.4.2).

*Graphical determination of the stationary forces on body-annular wing configurations with circular cross-sections in linearized supersonic flow. F. van der Walle. N.L.L. T.N. G.*9. *January* 1960.—(1.6.1 × 1.10.1.2).

STABILITY AND CONTROL *see also* EXTRA-ATMOSPHERIC TECHNOLOGY

Measurements of pitching oscillation derivatives at subsonic and transonic speeds for a cropped delta wing of aspect ratio 1·8. *(Interim Report). C. J. W. Miles* et al. *C.P.*534. 1961.—(1.8.2.2).

Aerodynamic characteristics in pitch and sideslip of a 1/15-scale model of the Scout vehicle at a Mach number of 2·01. *R. B. Robinson. N.A.S.A. T.N. D-793. May* 1961.
The effects of two sets of cruciform fins, of inline and indexed fin arrangements, a flare, and accessories such as antennaes, launch fittings, and control tunnels on the aerodynamic characteristics of the configuration were measured for combined angles of attack and sideslip to about 8°.—(1.8.1.2 × 1.8.2.2).

Transonic wind-tunnel investigation of the static longitudinal aerodynamic characteristics of several configurations of the Scout vehicle and of a number of related models. T. C. Kelly. N.A.S.A. T.N. D-794. May 1961.—(1.8.2.2).

Investigation at high subsonic speeds of the use of low auxiliary tail surfaces having dihedral to improve the longitudinal and directional stability of a T-tail model at high lift. W. C. Sleeman. N.A.S.A. T.N. D-804. April 1961.—(1.8.0.2).

Tolerable limits of oscillatory accelerations due to rolling motions experienced by one pilot during automatic-interceptor flight tests. R. F. Brissenden et al. *N.A.S.A. T.N. D-810. April* 1961.—(1.8.1.1 × 5).

Effects of gyroscopic cross coupling between pitch and roll on the handling qualities of V.T.O.L. aircraft. J. F. Garren. N.A.S.A. T.N. D-812. April 1961.
An experimental and theoretical investigation indicates the extent to which the amount of cross coupling present in an aircraft is dependent on the angular-velocity damping and moments of inertia of the aircraft as well as the angular momentum of the engine. A criterion based on pilots' opinions obtained from the simulation flights provides a means for determining the acceptability of cross coupling in V.T.O.L. aircraft as a function of the aircraft design parameters.—(1.8.0.1 × 3.12).

Transonic aerodynamic characteristics of a wing-body combination having a 52·5° sweptback wing of aspect ratio 3 with conical camber and designed for a Mach number of √2. *W. B. Igoe* et al. *N.A.S.A. T.N. D-817. May* 1961.—(1.8.2.2).

Transonic investigation of aerodynamic characteristics of a swept-wing fighter-airplane model with leading-edge droop in combination with outboard chord-extensions and notches. C. F. Whitcomb and H. T. Norton. N.A.S.A. T.N. D-834. May 1961.—(1.8.2.2 × 1.3.7).

Aerodynamic characteristics over a Mach number range of 1·40 to 2·78 of a rocket-propelled airplane configuration having a low 52·5° delta wing and an unswept horizontal tail. A. B. Kehlet. N.A.S.A. T.N. D-836. May 1961.
Characteristics of trim, drag, pitch damping, and longitudinal stability are presented. Theoretical comparisons of lift and longitudinal stability as well as experimental results from a similar configuration are included.—(1.8.2.2).

Aerodynamic characteristics in pitch of a series of cruciform-wing missiles with canard controls at a Mach number of 2·01. M. L. Spearman. N.A.S.A. T.N. D-839. May 1961.—(1.8.2.2.).

Analog-computer investigation of effects of friction and preload on the dynamic longitudinal characteristics of a pilot-airplane combination. H. L. Crane. N.A.S.A. T.N. D-884. May 1961. —(1.8.2.1).

Investigation of low-subsonic flight characteristics of a model of a hypersonic boost-glide configuration having a 78° delta wing. J. W. Paulson and R. E. Shanks. N.A.S.A. T.N. D-894. May 1961.
Flight tests were made over an angle-of-attack range from 10° to 35° with and without artificial pitch and roll damping added. Force tests were made from −4° to 40° angle-of-attack to determine the static stability and control characteristics and from 0° to 30° angle-of-attack to determine the dynamic stability derivatives.—(1.8.1.2 × 1.8.2.2).

Low-speed investigation of the effects of frequency and amplitude of oscillation in sideslip on the lateral stability derivatives of a 60° delta wing, a 45° sweptback wing, and an unswept wing. J. H. Lichtenstein and J. L. Williams. N.A.S.A. T.N. D-896. May 1961.—(1.8.1.2).

THERMO-AERODYNAMICS *see also* BOUNDARY LAYER

Exploratory investigation of transpiration cooling of a 40° double wedge using nitrogen and helium as coolants at stagnation temperatures from 1,295°F to 2,910°F. B. Rashis. N.A.S.A. T.N. D-721. May 1961.—(1.9.1 × 34.3.4).

Measurements of aerodynamic heat transfer and boundary-layer transition on a 10° cone in free flight at supersonic Mach numbers up to 5·9. C. B. Rumsey and D. B. Lee. N.A.S.A. T.N. D-745. May 1961.—(1.9.1 × 1.1.2.4).

Heat-transfer tests of 20-millimetre projectiles at a Mach number of 5 with an analysis by unsteady scaling laws to predict component temperature rises after firing for various free-flight conditions. R. L. Trimpi et al. *N.A.S.A. T.N. D-758. May* 1961.—(1.9.1).

Free-flight aerodynamic-heating data to Mach number 10·4 for a modified Von Kármán nose shape. W. M. Bland and K. A. Collie. N.A.S.A. T.N. D-889. May 1961.—(1.9.1).

WINGS AND AEROFOILS *see also* COMPRESSIBLE FLOW
FLUID DYNAMICS
LOADS

High Reynolds number tests on an unswept 11% thick R.A.E. 101 section aerofoil. R. W. F. Gould et al. *C.P.531.* 1961.—(1.10.2.1).

A wind tunnel investigation into the pressure distribution on a wing surface in a non-uniform supersonic flow. M. C. P. Firmin and W. J. Bartlett. C.P.551. 1961.—(1.10.2.2 × 1.6.1).

Low-speed wind-tunnel tests on a series of uncambered slender pointed wings with sharp edges. D. H. Peckham. R. & M. 3186. 1961.
A series of three thick uncambered slender wings and twelve flat-plate slender wings, all with sharp edges have been tested in the 13ft. x 9ft. Low-Speed Wind Tunnel at the Royal Aircraft Establishment, Bedford. Pressure plotting, balance measurements and flow-visualisation tests were made to investigate the effects of plan-form shape, thickness and aspect ratio on their aerodynamic characteristics at low speeds.—(1.10.2.2 × 1.6.1).

A method of determining aerodynamic-influence coefficients from wind-tunnel data for wings at supersonic speeds. P. A. Gainer. N.A.S.A. T.N. D-801. April 1961.—(1.10.2.2 × 1.6.1 × 33.2.3.2.5).

HELICOPTER AERODYNAMICS

Tables and charts of the normal component of induced velocity in the lateral plane of a rotor with harmonic azimuthwise vorticity distribution. H. H. Heyson. N.A.S.A. T.N. D-809. April 1961.—(1.11.3).

TESTING AND INSTRUMENTS *see also* COMPRESSIBLE FLOW
SCIENCE—GENERAL

Design of a large, two-stage, light-gas model launcher. W. B. Stephenson and D. E. Anderson. A.E.D.C-T.R.-61-6. June 1961.
A procedure is outlined for computing the performance of two-stage, light-gas launchers using helium as a propellant. The effects of the physical variables; geometry, piston mass, and pressures, are discussed. Design criteria are established for a large launcher which will be built for the Arnold Center (A.F.S.C.) ballistic range facility. Theoretical performance curves are included as well as experimental results obtained from two small launchers.—(1.12.1.3).

Development of hypervelocity range techniques at Arnold Engineering Development Center. J. Lukasiewicz et al. *A.E.D.C.-T.R.-61-9. June* 1961.
Development of a hypervelocity launcher and range instrumentation in preparation for operation of a 1,000-ft. aeroballistic facility is described. A method has been evolved for the gas-dynamics design of two-stage, light gas launchers. Performance, limitations, and mechanical design features of such launchers are discussed. Instrumentation developments include: (1) projectile radiation actuated detector and spark trigger, (2) simple, Fresnel-lens shadowgraph performing satisfactorily at projectile speeds of 26,000 ft./sec., (3) telemeter capable of transmitting model pressure measurements at launch accelerations of 200,000 g, (4) microwave velocity measuring technique.—(1.12.1.3).

A forced-oscillation balance system for the von Kármán facility 40- by 40-inch supersonic tunnel. C. J. Welsh et al. *A.E.D.C.-T.N.-61-63. May* 1961.
Measured damping-in-pitch derivatives for a flared after-body re-entry shape at $M_\infty = 4$ over a Reynolds number range from $0{\cdot}37 \times 10^6$ to $0{\cdot}58 \times 10^6$ based on body diameter are presented.—(1.12.4).

The measurement of pressure fluctuations in a hypersonic wind tunnel. M. D. Brown and P. L. Clemens. A.E.D.C.-T.N.-61-64. June 1961.—(1.12.1.3 × 1.5.1.4 × 1.12.5).

Further development of an inductance-driven hotshot tunnel. J. A. van der Bliek et al. *A.E.D.C.-T.N.-61-80. July* 1961.—(1.12.1.3).

Determination of test-section, after-shock, and stagnation conditions in hotshot tunnels using real nitrogen at temperatures from 3000 to 4000°K. M. Grauau et al. *A.E.D.C.-T.N.-61-82. July* 1961.—(1.12.1.3 × 1.2.3).

An investigation of free piston compression of shock tube driver gas. R. J. Stalker. N.R.C. Report M.T.-44. May 1961.—(1.12.1.3).

Überlegungen und bisherige Erfahrungen beim Bau des Heisswassercanals der D.F.L. n Braunschweig. O. Lutz und E. Riester. 1961. *(In German). D.F.L.-Berich* 149.—(1.12).

AEROELASTICITY

See also STRUCTURES—LOADS

An investigation of the flutter of rectangular wings with tip masses. Part 1. *Outline of project and results. R. J. Rockliff* et al. *W.R.E. Report H.S.A.* 5. *November* 1960.
Experimental results of a programme of trials of ground launched rocket boosted flutter test vehicles are presented and correlated with a 6 degree of freedom arbitrary mode analysis. The factors determining the critical type of flutter are discussed.—(2 × 33.1.2).

AIRCRAFT

See AERODYNAMICS—STABILITY & CONTROL
AIRCRAFT OPERATION
FATIGUE
FLIGHT TESTING

DESIGN AND CONSTRUCTION

See AIRCRAFT OPERATION

AIRCRAFT OPERATION

See also STABILITY AND CONTROL

Aerodynamic characteristics of parachutes at Mach numbers from 1·6 *to* 3. *J. D. Maynard. N.A.S.A. T.N. D-752. May* 1961.
Flow studies of both rigid- and flexible-parachute models were made by means of high-speed schlieren motion pictures, and drag coefficients of the flexible models were measured at simulated altitudes from about 50,000 to 120,000 feet.—(5.3).

Skid landings of airplanes on rocker-type fuselages. W. L. Mayo. N.A.S.A. T.N. D-760. May 1961.
A study is made of rocking on a curved fuselage under-surface, following impact of the tail or nose, to convert vertical energy in landing into the energy of a pitching oscillation in which wing lift changes and aerodynamic damping are important. Computations of the load and motions for particular shapes, and shapes for particular load applications, are made for selected aeroplanes. A dynamic model of one of these aeroplanes was tested to check the computations for impact and to provide additional information relative to the stability of the landing runout.—(5.3 × 4.2.2.3 × 33.2.3.5).

An investigation of duties in the Electra cockpit. J. R. Baxter and R. H. Day. A.R.L. Note H.E. 9. *March* 1961.—(5.1 × 3.6).

ANIMAL FLIGHT

See INSTRUMENTS & EQUIPMENT

EXTRA-ATMOSPHERIC TECHNOLOGY

See also MATHEMATICS
SCIENCE—GENERAL

The effect of radiation force on satellites of convex shape. H. B. Holl. N.A.S.A. T.N. D-604. May 1961.—(8.2 × 32.2).

Satellite magnetic field mapping. J. P. Heppner et al. *N.A.S.A. T.N. D-696. May* 1961.
The topics discussed include the accuracy of spherical harmonic analyses of the earth's field, possible magnetic field discontinuities associated with the inner radiation belt, and magnetic storm effects.—(8.1 × 32.2).

Experimental evaluation of the deceleration of aluminium cylinders rotating in a magnetic field and comments on magnetic damping of a flywheel control. D. G. Eide. N.A.S.A. T.N. D-749. April 1961.—(8.2).

Effects of mass-loading variations and applied moments on motion and control of a manned rotating space vehicle. W. D. Grantham. N.A.S.A. T.N. D-803. May 1961.—(8.2 × 1.8.0.1 × 33.1).

Experimental investigation of stage separation aerodynamics. R. A. Wasko. N.A.S.A. T.N. D-868. May 1961.—(8.2).

Orbital elements of photographic meteors. R. E. McCrosky and A. Posen. Smithsonian Cont. Astro. Vol. 4. *No.* 2. 1961.—(8.1).

Gaps in the distribution of asteroids. Y. Hagihara. Smith. Conts. Astro. Vol. 5. *No.* 6. 1961.—(8.1).

Major flares and geomagnetic activity. B. Bell. Smith. Conts. Astro. Vol. 5. *No.* 7. 1961.—(8.1).

An annotated bibliography on interplanetary dust. P. W. Hodge et al. *Smith. Conts. Astro. Vol.* 5. *No.* 8. 1961.—(8.1 × 30.1).

Raumfahrtantriebe Stand der Grundlagenforschung und der Entwicklung. G.Au. D.F.L. Bericht 144. 1961.—(8.2 × 27 × 30.1).

ELECTRONICS

See MATERIALS

FLIGHT TESTING

See also AERODYNAMICS—COMPRESSIBLE FLOW
MISSILES

Hovering and transition flight tests of a 1/5*-scale model of a jet-powered vertical-attitude V.T.O.L. research airplane. C. C. Smith. N.A.S.A. T.N. D-404. May* 1961.
This vertical-attitude aeroplane, which is powered by a single turbojet engine, has a triangular wing mounted high on the fuselage with a triangular tail on top of the wing and has no horizontal tail. The aeroplane has conventional elevon and rudder controls for use in normal flight and has jet-reaction controls for use in hovering and at low air speeds. The investigation included stability and control flight tests of the basic model configuration and also a study of the effects of engine gyroscopic moments on stability and control.—(13.2 × 3.12).

INSTRUMENTS AND EQUIPMENT

See also STRUCTURES—TESTING

Repeatability of the over-all errors of an airplane altimeter installation in landing-approach operations. W. Gracey and J. W. Stickle. N.A.S.A. T.N. D-898. May 1961.
The results of flight tests to determine the over-all altimetry errors of the service altimeter installation of a transport aeroplane in the landing-approach condition are presented. Data on two sensitive altimeters and four precision altimeters were obtained for a speed range of 62 to 100 knots during 42 landing approaches.—(18 × 26 × 7.1.1).

A photo-electric device for the measurement of quantity of liquid. R. Sandri. N.R.C. Report M.I. 822. *September* 1961.
Photo-electric device producing an output voltage which is a linear function of the quantity of liquid contained in the measuring tube is described. A detailed description is given of the optical system, its function and possible sources of error. Finally, the method of calibration of the system is described. The apparatus can follow rapid changes of quantity of liquid.—(18.1 × 32.2.4).

Electrical noise level measurements of N.R.C. mercury sliprings rotating at 12,000 *r.p.m. and a surface rubbing speed of* 70 *ft./sec. T. H. Hammell. N.R.C. Test Report M.E.T.-283. April* 1961.
Electrical noise level tests on N.R.C. mercury slip-rings were carried out to determine their suitability for use with strain gauges at 12,000 r.p.m.—(18.1).

MATERIALS

A survey of the development of contour etching with particular

reference to the effects on tensile and fatigue strength of alclad alloys of aluminium. E. M. Cowburn. C.o.A. Report 137. *April* 1961.
Experiments to develop a production technique are described and factors controlling the process and product are discussed. The considerable advantages of the process in the production of aircraft are shown in some detail.—(21.2.2).

An initial assessment of graphite as a structural material in conditions of high thermal flux. A. J. Kennedy. AGARDograph 51. *September* 1960.
The erosion of graphite, the use of coatings, the addition of vapourising compounds and the development of new graphites are discussed. Considerations relating to thermal shock, creep and fabrication are surveyed.—(21.3).

The behaviour of beryllium and beryllium copper in a 4,000°*F supersonic air jet at a Mach number of* 2. *William H. Kinard. N.A.S.A. T.N. D-*806.—(21.2.2).

Electrical characteristics of four ternary platinum-rhodium-base alloys containing chromium, cobalt, or ruthenium. H. H. Lowell et al. *N.A.S.A. T.N. D-*867. *May* 1961.—(21.2 × 11).

*The propaedeutics of natural, synthetic and beneficiated asbestos. J. M. Trenouth. N.R.C. Report M.S.-*105. *March* 1961.

The results of a literature survey on natural and synthetic asbestos are presented. The following topics have been dealt with: varieties and compositions, origin, physical properties, structure, synthesis, beneficiation, and substitutes.—(21.3.2).

MATHEMATICS

*Simultaneous least-squares approximation of a function and its first integrals with application to thermodynamic data. F. J. Zeleznik and S. Gordon. N.A.S.A. T.N. D-*767. *May* 1961.
A method is presented for the simultaneous least-squares approximation of a function and its first integrals subject to the constraint that the residuals vanish at some point in the interval of the fit. This method is applied to fitting empirical equations to the thermodynamic functions heat capacity, enthalpy, and entropy.—(22.1 × 34).

On the motion of satellites with critical inclination. Smith. Conts. Astro. Vol. 5. *No.* 5. 1961.—(22.2 × 8.2).

MECHANICAL ENGINEERING

See SCIENCE—GENERAL

MISSILES

See also AERODYNAMICS—FLUID DYNAMICS

Free-flight measurements of the zero-lift drag and base pressure on a wind tunnel interference model ($M = 0{\cdot}8$-$1{\cdot}5$). *G. H. Greenwood. C.P.*553. 1961.—(25.2 × 13.3).

NAVIGATION

See AERODYNAMICS—COMPRESSIBLE FLOW
INSTRUMENTS & EQUIPMENT
SCIENCE—GENERAL

POWER PLANTS

See also EXTRA-ATMOSPHERIC TECHNOLOGY

*An analytical and experimental study of the thermal boundary layer and ebullition cycle in nucleate boiling. Y-Y Hsu and R. W. Graham. N.A.S.A. T.N. D-*594. *May* 1961.—(27.3 × 32.1).

An experimental investigation of the damping of liquid oscillations in cylindrical tanks with various baffles. M. A. Silveira et al. *N.A.S.A. T.N. D-*715. *May* 1961.
Data show the variations of damping and natural frequency with baffle configuration, width, and location as well as the effects of the amplitude of the liquid oscillations and of the kinematic viscosity on the damping factor. The damping results are presented in dimensionless form and are compared where possible with those determined by semiempirical analytical methods.—(27.3 × 33.1.2).

Comparative measurements of beam power in ion-rocket research. E. A. Richley et al. *N.A.S.A. T.N. D-*845. *May* 1961. —(27.7).

*Experimental evaluation of analytical models for the inertias and natural frequencies of fuel sloshing in circular cylindrical tanks. R. W. Warner and J. T. Caldwell. N.A.S.A. T.N. D-*856. *May* 1961.—(27.3 × 33.2.4.3.10).

PROPELLERS

*Method for calculating induced velocities at the blades of a slightly inclined propeller with constant circulation. H. E. Heyson. N.A.S.A. T.N. D-*818. *May* 1961.—(29.1).

REFERENCE LITERATURE

See EXTRA-ATMOSPHERIC TECHNOLOGY

FATIGUE

Fatigue tests on "Mustang" wings and notched aluminium alloy specimens under random gust loading with and without ground to air cycle of loading. J. Y. Mann and C. A. Patching. A.R.L. Note S.M. 268. *March* 1961.
Results are presented for fatigue tests on "Mustang" wings and notched specimens, under a load sequence representative of flight loading both with and without ground to air cycles.—(31.2.2.3.2 × 31.2.4.2 × 3.6).

SCIENCE—GENERAL

See also AERODYNAMICS—FLUID DYNAMICS
EXTRA-ATMOSPHERIC TECHNOLOGY
INSTRUMENTS AND EQUIPMENT
POWER PLANTS
STRUCTURES—TESTING

Transmission device for reversibility of rotation with extremely fast action. J. Boehm et al. *N.A.S.A. T.N. D-*603. *May* 1961.—(32.2 × 23.3).

*A geoid and world geodetic system based on a combination of gravimetric, astro-geodetic, and satellite data. W. M. Kaula. N.A.S.A. T.N. D-*702. *May* 1961.—(32.2 × 26 × 8.2).

The interaction of a rarefaction wave with a wire grid. R. E. Center. A.R.L. Report A. 118. *December* 1959.—(32.2 × 1.12.6).

STRUCTURES

LOADS *see also* AERODYNAMICS—LOADS
AEROELASTICITY
EXTRA-ATMOSPHERIC TECHNOLOGY
POWER PLANTS

Experimental studies of flutter of buckled rectangular panels at Mach numbers from 1·2 *to* 3·0 *including effects of pressure differential and of panel width-length ratio. M. A. Sylvester. N.A.S.A. T.N. D-*833. *May* 1961.
An estimated flutter boundary is presented for buckled panels clamped on four edges, with width-length ratios of 0·21 to 4·0. The results of limited tests on panels with applied damping, curvature, and lengthwise stiffeners are also presented and discussed.—(33.1.2 × 33.2.4.5.6 × 2).

THEORY AND ANALYSIS *see also* AERODYNAMICS—LOADS
WINGS AND AEROFOILS
AIRCRAFT OPERATION
POWER PLANTS
STRUCTURES—LOADS

Buckling due to thermal stress of cylindrical shells subjected to axial temperature distributions. D. J. Johns et al. *C.o.A. Report* 147. *May* 1961.
Thermal stress distributions in uniform circular cylindrical shells due to axial temperature distributions are investigated. The discontinuity effect due to the pressure of a cooler stiffening bulkhead is considered, and the possibility of thermal buckling of the shell due to the circumferential discontinuity stress is examined. The buckling analysis is based on Donnell's shell equation, and particular attention is given to shells having clamped edges. An experimental investigation of this buckling problem is discussed.—(33.2.4.3.9).

*Finite elastic analysis of an infinite plate with an elliptic hole. I. Plane strain. G. Lianis. Purdue Univ. Report S.-*61-1. *May* 1961.
A theory of finite elasticity is employed to investigate the stresses and displacements of a plate having an elliptic hole. The directions of the principal stresses at infinity form an angle with the axes of the ellipse. A perturbation method is used in connection with the complex variable theory of plane elasticity. A closed form solution is found for the general problem.—(33.2.1 × 33.2.4.5).

TESTING

Errors in strain gauge bridge networks. I. G. Scott. A.R.L. Report S.M. 276. *August* 1960.
A study is made of various commonly used bridge networks, particular attention being paid to the small errors frequently ignored in simple analysis.—(33.3.1 × 18.1 × 32.2.1).